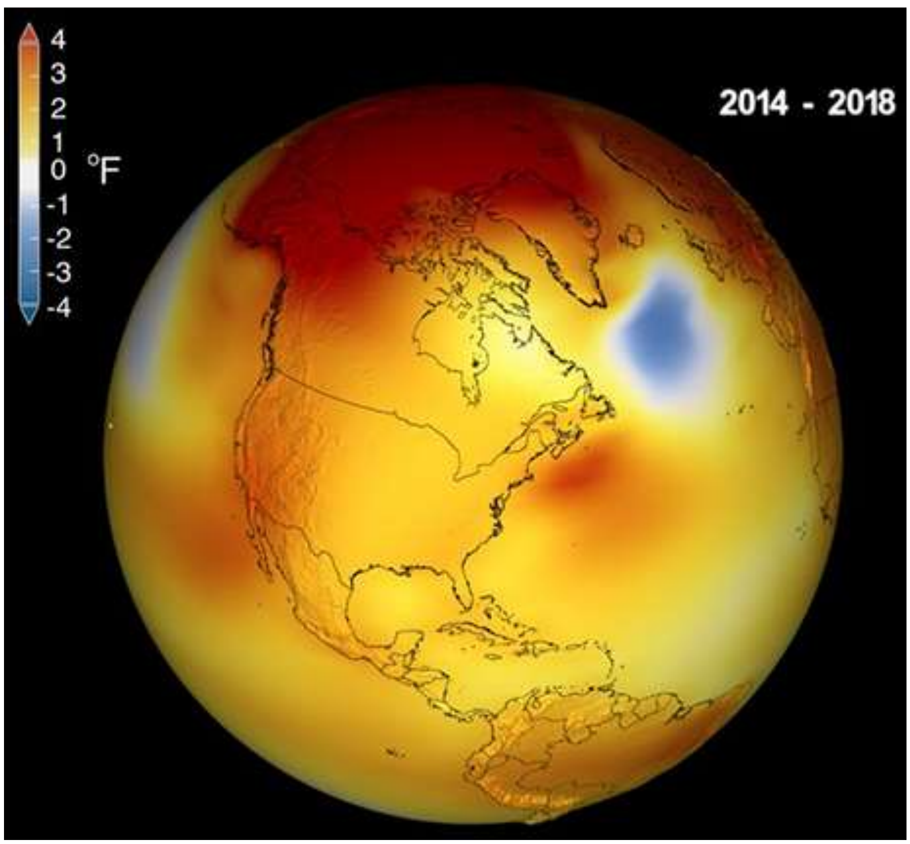
National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Changes in Climate & Wildfires

NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



I. Executive Summary

The title of this unit is Changes in Climate & Wildfires and will allow students to investigate how climate plays a role in increasing the risk of wildfires around the world. The unit is centered around the following anchor phenomenon: The amount and intensity of wildfires has been increasing. Although wildfires can be started by both human and natural causes, changes to a location's climate can increase the likelihood of a wildfire. Dry and warm environmental conditions are favorable to the development of wildfires. Students will utilize NASA datasets to investigate how Arctic Amplification and teleconnections such as the El Niño Southern Oscillation (ENSO) and the Arctic Oscillation (AO) lead to those environmental conditions.

Teleconnections describe the relationship between changes in climate for locations that are large distances apart. ENSO is a prominent example of a teleconnection that is characterized by changes in wind patterns, sea level pressure, and sea surface temperature in the eastern equatorial Pacific Ocean. ENSO has a warm phase known as El Niño, a cold phase known as La Niña, and a neutral phase. Each phase of ENSO can impact temperature and precipitation patterns across a variety of regions around the world. While some locations can experience drought due to ENSO, other locations can experience increased rainfall and severe flooding. The strong El Niño event that took place from 2015 to 2016 can be related to the wildfires that took place in the Amazon and the Philippines as a result of reduced rainfall in both locations.

The Arctic Oscillation (AO) is another example of a teleconnection characterized by changes in pressure in the North Atlantic Ocean. The AO has a positive phase and a negative phase, and each phase influences the location of the polar jet stream. The positive phase of the AO leads to a strong polar jet stream that is situated further north in the Arctic, which confines the cold Arctic air. On the other hand, the negative phase of the AO leads to a weaker polar jet stream that shifts further south and brings the cold polar air with it. The heat waves and wildfires in Siberia in 2020 are linked to a prolonged positive phase of the AO due to the persistent high pressure, warm temperature, and lack of precipitation.

This unit also allows students to learn how global warming is leading to unequal changes in temperature around the world, specifically within the Arctic regions. The students will develop meaning of the term Arctic Amplification and learn how and why the Arctic is experiencing greater increases in temperature due to changes in surface albedo. As the Arctic regions warm, the snow and ice cover decreases, decreasing surface albedo. This leads to more absorption of energy, which increases temperature even more. Due to this phenomenon, regions in the Arctic have been experiencing more wildfires as warmer and drier conditions develop.

As temperature on Earth continues to warm, the negative impacts of climate change are going to become more prevalent and widespread. It is essential for the students to learn how these teleconnections and Arctic Amplification play a role in increasing the number of wildfires. As climate continues to change and wildfires become more frequent, having the knowledge of the atmospheric patterns that lead to wildfires can enhance mitigation and adaption strategies.

II. Introduction Goals and Overview of Unit

This unit titled Changes in Climate & Wildfires will allow students to investigate different climate-related factors that can increase the number of wildfires on Earth. Specifically, the students will explore how Arctic Amplification and teleconnections such as the El Niño Southern Oscillation (ENSO) and the Arctic Oscillation (AO) can lead to environmental conditions that are conducive to the start and spread of wildfires. Wildfires can become more widespread when the environmental conditions are dry and warm, and the students will be able to explain why the conditions develop based on changes to climate patterns. The unit is based on the following anchor phenomenon:

The amount and intensity of wildfires has been increasing.

The unit is structured to include five different lessons. The first is a lesson that launches the anchor phenomenon, the next three lessons follow the 5E model and are based on a specific investigative phenomenon, and the last lesson includes the final assessment activity.

The students will begin the unit completing a one-day lesson that introduces them to the anchor phenomenon that will drive the unit. The goal of this lesson is to identify student knowledge of wildfires in regard to what they are, where they occur, and how climate plays a role. The lesson will begin with students viewing a NASA simulation that shows the amount and extent of global carbon emissions from fires between 2013 and 2018. Based on the content in the simulation, the students will complete a See, Think, Wonder chart and then use a blank world map to color-code the locations that experience frequent wildfires. The students will be able to learn about natural wildfires and also fires that are intentionally set for agricultural purposes. The students will uncover the environmental conditions conducive to wildfires and end the lesson with a discussion about how climate change has and will continue to impact the number and intensity of wildfires.

The next lesson is the first 5E lesson of the unit and is titled El Niño Southern Oscillation (ENSO). The investigative phenomenon for this lesson is:

The El Niño Southern Oscillation (ENSO) can influence global climate patterns.

The goal of this lesson is for the students to learn about the warm, cold, and neutral phases of ENSO and how each phase influences temperature and precipitation around the world. The students will use NASA's Panoply software to explore sea surface temperature anomaly and precipitation anomaly data to uncover how environmental conditions change as a result of each ENSO phase. The students will then use a simulation from Prentice Hall that shows the development of El Niño and La Niña conditions from the normal (neutral) ENSO phase. Specifically, the students will be analyzing the changes to surface ocean currents and winds in the equatorial Pacific Ocean to ultimately explain why each ENSO phase is associated with changes in sea surface temperature and precipitation in the equatorial Pacific Ocean. Towards the end of the lesson, the students will utilize their knowledge of ENSO to make connections between the 2015 – 2016 El Niño event and wildfires in the Amazon.

The next 5E lesson is titled Arctic Amplification and is based on the following investigative phenomenon:

The Arctic regions have been warming at a greater rate than other regions around the world.

The goal of this lesson is for the students to learn why the Arctic region is experiencing the greatest increase in temperature due to climate change. The students will begin the lesson by making predictions about the locations around the world they believe are experiencing the greatest and least increases in temperature. Then, the students will use NASA's GISTEMP site to create global surface temperature anomaly maps for the years 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2019. Based on the maps, the students will be able to identify that the Arctic regions have experienced the greatest increases in temperature when compared to other locations around the world. To determine why the temperature in the Arctic has been increasing the most, the students will read a NASA Earth Observatory article titled Arctic Amplification, watch a NASA video titled This World is Black and White, and use NASA's Panoply software to investigate the surface albedo in the Arctic. By the end of the lesson the students will be able to explain the meaning of Arctic Amplification through the changes in surface albedo that results from the melting of snow and ice. When albedo decreases, more solar energy can be absorbed in the Arctic, which increases temperature even more. Towards the end of the lesson, the students will make connections between Arctic Amplification and the development of wildfires in the Arctic region.

The last 5E lesson of the unit is titled Atmospheric Teleconnections and is based on the following investigative phenomenon:

The change in temperature and pressure in one region of the world can influence weather patterns in another region.

The goal of this lesson is for the students to learn about the term "teleconnection" in relation to the El Niño Southern Oscillation (ENSO) and the Arctic Oscillation (AO). The students will begin the lesson by working to define the term "teleconnection" based on the content within the NASA video titled How the 2015 – 2016 El Niño Triggered Outbreaks Across the Globe. Since the students learned about ENSO in a previous lesson, the students will have the opportunity to explore the AO and its impacts. The students will use NASA's Panoply software, sea level pressure anomaly data, and precipitation anomaly data to learn about the atmospheric conditions during the positive and negative phases of the AO. Specifically, the students will focus on the North Atlantic Ocean, which is the region in which the AO is measured, and eastern Siberia, a region whose climate is impacted by the AO. The students will learn about the AO through the lens of the heat wave and increased wildfires in Siberia through the first half of 2020. The students will then read a text from the National Snow and Ice Data Center titled Arctic Oscillation and create diagrams to illustrate changes in the polar jet stream, air pressure, and temperature in the North Atlantic Ocean and eastern Siberia as a result of the positive and negative phases of AO. Towards the end of the lesson, the students will further investigate ENSO as a teleconnection and its impact on global climate. The students will use RStudio and the R programming language to run a script created by NASA GISS scientists that analyzes the relationship between the December/January ENSO phase and annual global surface temperature anomalies. With this information, the students will be able to predict the following year's annual average temperature anomaly based on the current year's December/January ENSO index.

The last lesson of the unit is based on the final assessment activity. In this activity, the students will be in pairs and each student is responsible for completing Event #1: 2015 – 2016 Wildfires in the Southern Philippines or Event #2: Summer 2019 Wildfires in Alaska. Event #1 is based on the impacts of ENSO and

Event #2 is based on the impacts of Arctic Amplification. Students will use NASA's Panoply software and the resources acquired throughout the unit to explain how and why climate played a role in the wildfires that occurred during each event. Once the students gather the necessary information, they will create a presentation to teach their partner about the factors that led to their wildfire event.

III. Educator Biography

Nicole Dulaney – Earth Science & STEM Educator
nmd46@cornell.edu

Nicole Dulaney has been teaching Earth Science since September 2013. She began her career in the New York City Department of Education (NYCDOE) and spent six years teaching at Hillcrest High School in Jamaica, Queens. During her time in the NYCDOE, Nicole was a Math *for* America Early Career Fellow where she led and participated in over fifty professional development workshops for STEM educators.

From September 2019 to August 2020, Nicole taught 8th grade Earth Science in the Tuckahoe Union Free School District (UFSD). Nicole recently started working at Bethpage UFSD teaching high school Earth Science and looks forward to enhancing the STEM offerings and opportunities for her students.

Nicole's interest in STEM education can be traced back to her childhood, when she would often track East Coast Winter Storms. She is grateful to have a career in a field that merges her passion of STEM content and education, and she looks forward to empowering the next generation of STEM leaders. Nicole earned a Bachelor of Science in Atmospheric Science *cum laude* from Cornell University and a Master of Arts in Adolescent Education from Hunter College.

Over her career, Nicole has participated in two research programs for STEM educators. During the summers of 2014 and 2015, she participated in the Columbia University Summer Research Program for Science Teachers. From 2015 to 2018, Nicole worked as an associate researcher with the NASA GISS Climate Change Research Initiative (CCRI). Through her research experience with CCRI, Nicole created a STEM Earth Science research class at Hillcrest High School. The course began in September 2016 and introduced students to Earth's climate system. In this course, students learn about past, present and future climate change; the course heavily leverages on NASA resources. Students end the year engaging in a group-based research project about a topic related to climate change.

IV. Table of Contents

Clicking on each component of the Table of Contents will bring you directly to the location in the document.

V. Next Generation Science Standards (NGSS) Alignment

Grade	8th (honors), 9th – 12th
Unit Duration	All lessons are based on a 50-minute class period. Each lesson duration is an estimate and will depend on the prior knowledge of students and ability to use Panoply and RStudio. • Lesson #1 – Introduction to Anchor Phenomenon: 1 day • Lesson #2 – El Niño Southern Oscillation (ENSO): ~4 days • Lesson #3 – Arctic Amplification: ~ 3 days • Lesson #4 – Atmospheric Teleconnections: ~7 days • Lesson #5 – Final Assessment Activity: ~4.5 days
Phenomenon	**Anchor Phenomenon:** The amount and intensity of wildfires has been increasing. **Investigative Phenomenon (Lesson #2)**: The El Niño Southern Oscillation (ENSO) can influence global climate patterns. **Investigative Phenomenon (Lesson #3)**: The Arctic regions have been warming at a greater rate than other regions around the world. **Investigative Phenomenon (Lesson #4)**: The change in temperature and pressure in one region of the world can influence weather patterns in another region.
NGSS Performance Expectations	**HS-ESS2-2**. – Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to Earth's systems. **HS-ESS2-4. –** Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. **HS-ESS3-5** – Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems
NGSS Disciplinary Core Ideas	ESS2.A: Earth Materials and Systems ESS2.D: Weather and Climate ESS3.D: Global Climate Change
NGSS Science and Engineering Practices	Analyzing and Interpreting Data
NGSS Cross-cutting Concepts	Cause and Effect Stability and Change

VI. NASA Education Resources Utilized in Unit

A) Resources

Lesson #1 – Introduction to Anchor Phenomenon
- NASA-created simulation of global carbon emissions from wildfires between 2003 and 2018
- NASA article titled Satellite Data Record Shows Climate Change's Impact on Fires

Lesson #2 – El Niño Southern Oscillation (ENSO): 5E
- NASA GISS Panoply software
- NASA simulation showing the development of the 2015 El Niño
- NASA article titled El Niño Could Drive Intense Season for Amazon Fires
- NASA-sponsored GLOBE resource about ENSO
- NASA Earth Observatory Mapping the Amazon resource

Lesson #3 – Arctic Amplification: 5E
- NASA GISS Panoply software
- NASA/NOAA temperature anomaly map 1880 to 2019
- NASA GISS Surface Temperature Analysis (GISTEMP)
- NASA Earth Observatory Article titled Arctic Amplification
- NASA video titled This World is Black and White
- NASA ERBE Climatology average monthly albedo data
- NASA video titled NASA Studies How Arctic Fires Change the World
- NASA article titled NASA Studies How Arctic Wildfires Change the World
- NASA article titled NASA's Aqua Satellite Shows Siberian Fires Filling Skies With Smoke
- NASA resource titled The Study of Earth as an Integrated System
- NASA Research Feature titled Another Intense Summer of Wildfires in Siberia

Lesson #4 – Atmospheric Teleconnections: 5E
- NASA GISS Panoply software
- NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe
- NASA Earth Observatory article titled El Niño
- NASA's GISTEMP surface temperature anomaly data download
- NASA Earth Observatory article titled Heat and Fire scorches Siberia
- NASA GISTEMP data for use in RStudio

Lesson #5 – Final Assessment Activity
- NASA GISS Panoply software
- NASA Fire Information For Resource Management System (FIRMS)

B) Data Visualization and Analysis Activity

Lesson #1 – Introduction to Anchor Phenomenon
The intention of this lesson is to introduce students to the anchor phenomenon that will drive the content and instructional activities within the unit. Students will begin by analyzing the location of wildfires around the world based on a NASA simulation showing carbon emissions from fires between 2003 and 2018. This is the only visualization activity in this introductory lesson.

Lesson #2 – El Niño Southern Oscillation (ENSO): 5E
There are multiple data visualization activities in this lesson. The first two are in the Explore sections of the lesson in which the students use NASA's Panoply software to visualize sea surface temperature anomaly data and precipitation anomaly data along the equatorial Pacific Ocean during El Niño, La Niña, and ENSO neutral phases. In the Explain section, the students also use an ENSO simulation from Prentice Hall to visualize the changes to the atmosphere and the ocean in the equatorial Pacific Ocean during all phases of ENSO. Finally, during the Elaborate section, the students will use NASA's Panoply software to evaluate the sea surface temperature anomalies and precipitation anomalies that were observed during the 2015 – 2016 ENSO event that led to wildfires in the Amazon.

Lesson #3 – Arctic Amplification: 5E
The first data visualization activity in this lesson takes place in the Explore section in which the students use NASA's GISTEMP to create global surface temperature anomaly maps from 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2019. The goal is to identify the region of the world that experienced the greatest increases in temperature due to climate change. During the Explain section, the students engage in another data visualization activity by using NASA's Panoply software to display average monthly albedo data to make connections between changes in albedo and increasing temperatures in the Arctic.

Lesson #4 – Atmospheric Teleconnections: 5E
The Explore section of this lesson has two data visualization activities. The first has the students use NASA's Panoply to visualize sea level pressure anomaly data to characterize the changes in pressure in the North Atlantic Ocean during both phases of the Arctic Oscillation (AO). The students also explore how both phases of the AO influence air pressure in eastern Siberia. During the second Explore activity the students also use Panoply to display surface temperature anomalies from GISTEMP in eastern Siberia during both phases of the AO. The goal in this Explore section is to show the students how eastern Siberia's climate can be impacted by the AO. There is another data visualization and analysis activity in the Elaborate section of the lesson. In this activity, the students use RStudio and an RScript code created by NASA GISS scientists to create a graph that shows the relationship between the December/January phase of ENSO and the current & following year's temperature.

Lesson #5 – Final Assessment Activity
In the final assessment activity, the students will use NASA's Panoply software to create maps that display the sea surface temperature anomalies, precipitation anomalies, and surface air temperature anomalies during two different wildfire events. The students will use this data to explain how climate played a role in starting and spreading the wildfires during each event.

C) NASA Mission Alignment

The mission of the NASA Earth Science Division is rooted in helping society understand Earth's interconnected systems and how Earth will be impacted by both natural and human-induced changes to its systems. This entire unit is aligned to NASA's mission because each lesson is related to how changes within Earth's oceanic and atmospheric systems can lead to changes in climate, increasing the threat of wildfires. The El Niño Southern Oscillation (ENSO) and Arctic Oscillation (AO) are natural teleconnections discussed in Lessons #2 and #4 that can impact the climate in multiple regions across the world. During different phases of ENSO and the AO, climate conditions can change and become conducive to the start and spread of wildfires. Lesson #3 is based on Arctic Amplification and how the rate of global warming has been greater in the Arctic regions due to the melting of snow and ice and the drastic change in surface albedo of the region. The Arctic has been getting warmer and drier in some regions, increasing the opportunities for wildfires. The anchor phenomenon tying this unit together is based on the relationship between wildfires and changes in climate. NASA has multiple missions devoted to fire research and observing the real-time start and spread of wildfires. NASA's Terra and Aqua satellites have instruments that can locate wildfires based on their emissions. It is essential for us to gain an understanding of how changes in climate will impact the number and extent of wildfires so we can make better decisions in regard to climate change mitigation and adaptation strategies.

D) NASA 2018 Strategic Objectives Alignment

This unit plan relates directly to the NASA 2018 Strategic Goal #3 – Address National Challenges and Catalyze Economic Growth. Specifically, this unit aligns with Strategic Objective 3.3, which is to "Inspire and Educate the Public in Aeronautics, Space, and Science". NASA's missions allow for the public to view and analyze data such as NASA's GISTEMP surface temperature anomaly data. In each of the three 5E-structured lessons, students are also using NASA's Panoply software to engage in numerous data visualization activities. This unit allows the students to make connections between changes in climate and the increase in wildfires across multiple regions of the world. While some changes in climate are caused by natural phenomenon, there are other changes that are induced by human activity. Through NASA data and software, the students can draw their own conclusions regarding the changes in Earth's climate system and the relationship to wildfires. Under Strategic Goal #1, this lesson also aligns well with Strategic Objective 1.1 – Understand the Sun, Earth, Solar System, and Universe. Throughout the unit, the students are learning more about Earth's climate system through Arctic Amplification and teleconnections such as ENSO and the AO. The students will also make direct connections to the impacts of climate change and will be able to identify the regions of the world that are already the most vulnerable.

E) NASA Office of STEM Engagement Objectives Alignment

This unit plan is also aligned with the NASA Office of STEM Engagement objectives, specifically,

- 1.1 – Students contribute to NASA's endeavors in exploration and discovery.
- 2.1 – Students, including those from underrepresented and underserved communities, explore and pursue STEM pathways through authentic learning experiences and research opportunities with NASA's people and work.

Throughout the unit, students are exploring climate datasets such as NASA's GISTEMP through NASA's Panoply software. The activities within the unit give the students the opportunity to directly engage in the analysis products that result from NASA's endeavors. Through all lessons, students have the opportunity to pursue STEM pathways by conducting data analyses similar to the research performed daily by NASA scientists.

VII. Unit Pre & Post Standards-Based Assessment

Pre & Post-Unit Assessment

The pre and post-unit assessment is based on content from the Next Generation Science Standards (NGSS) at the high school level. The standards are listed below:

HS-ESS2-2. – Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to Earth's systems.

HS-ESS2-4. – Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS-ESS3-5 – Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

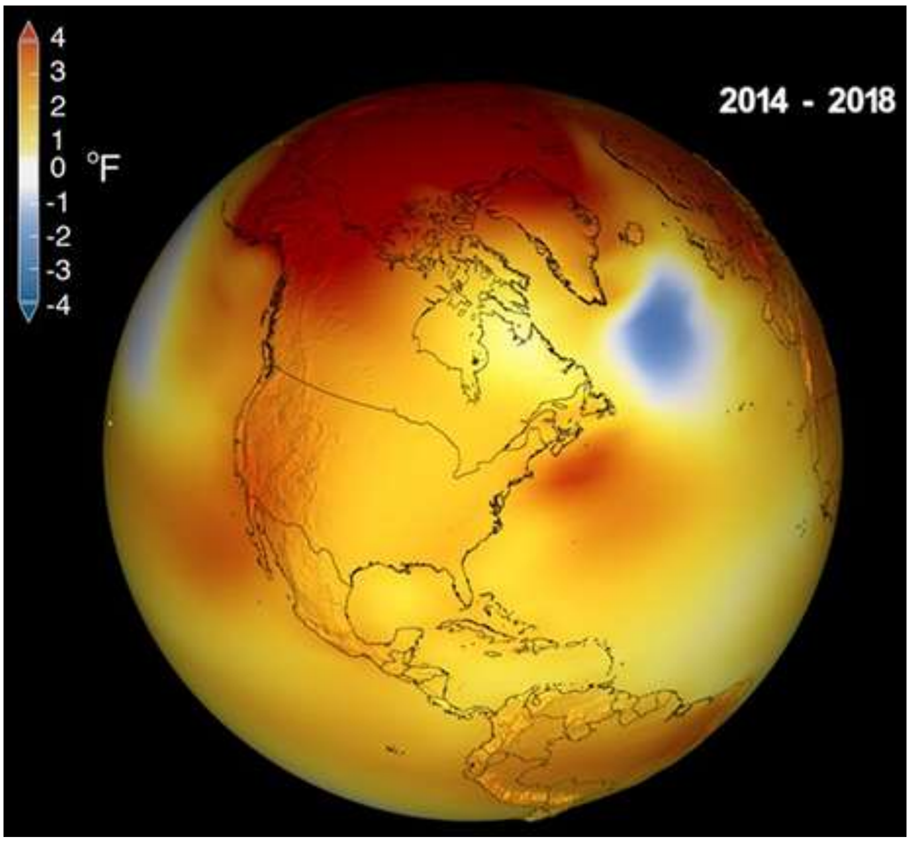
The pre-assessment is the activity in the first lesson that introduces the students to the unit's anchor phenomenon. The purpose of this activity is to learn what students know about wildfires in regard to how they start, where they occur, and how climate plays a role. This activity will also surface any major misconceptions the students have about wildfires that will need to be addressed throughout the unit.

The post-assessment is the final assessment activity in the last lesson of the unit. In the final assessment activity, the students will investigate how changes in climate influenced the 2015 – 2016 wildfires in the Philippines or the Summer 2019 wildfires in Alaska. The students will use the datasets acquired throughout the unit and NASA's Panoply software to uncover whether changes in climate that led to the wildfires are a result of the El Niño Southern Oscillation or Arctic Amplification. The students will then create a presentation to teach a classmate about the climate factors that led to their wildfire event.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Changes in Climate & Wildfires
Lesson #1 Title: Anchor Phenomenon
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



VIII. Lesson #1: Introduction to Anchor Phenomenon

A. Summary and Goals of Lesson

The goal of this lesson is to introduce the students to the anchor phenomenon that drives the overall unit. The anchor phenomenon is listed below:

The amount and intensity of wildfires has been increasing.

This lesson does not follow the 5E format since it is an introduction to the unit and is meant to get the students interested in the content. In this lesson, students will have the opportunity to demonstrate prior knowledge and expand on their thinking. The lesson also gives teachers the opportunity to learn about student misconceptions. The lesson begins with the students viewing a NASA simulation of carbon emissions from wildfires between 2003 and 2018. The students will complete a See, Think, Wonder chart and answer questions based on their observations from the simulation. The students will use the information from the simulation to explain why they believe wildfires occur within specific locations. The students will also identify the locations of wildfires that surprise them. Additionally, the students will have the opportunity to learn about natural causes of wildfires and about fires that are intentionally set for agricultural purposes. The students will also define the environmental conditions conducive to the start and spread of wildfires based on information in a NASA article titled Satellite Data Record Shows Climate Change's Impact on Fires. The lesson will end with the students engaging in a discussion about how they believe climate change has impacted the number and intensity of wildfires and how wildfires will be impacted in the future.

B. Table of Contents for lesson

C. Lesson Template

Introduce the Anchor Phenomenon Lesson Plan – Earth Science

Unit: Changes in Climate & Wildfires **Topic**: Introduction to Anchor Phenomenon

Anchor Phenomenon:

The amount and intensity of wildfires has been increasing.

Aim: Why do wildfires occur in different regions across the Earth?

Performance Objective: Students will be able to predict why specific regions around the Earth experience wildfires by engaging in a See, Think, Wonder activity and small group discussion based on a NASA simulation of carbon emissions from global wildfires.

Materials:

- Class set of computers

Links to electronic resources are provided below:

- Link to NASA simulation of carbon emissions from global wildfires between 2013 and 2018.
- Link to NASA article titled Satellite Data Record Shows Climate Change's Impact on Fires

Vocabulary:

- Carbon emissions
- Wildfires

Development of the Lesson: One-day lesson (1 class period)

What the teacher does	What the student does	Time
1. Ensure all students can access the NASA simulation of the carbon emissions from wildfires. Circulate the room as the students are completing their See, Think, Wonder chart. • As you circulate, ensure the students are making accurate observations about the location of wildfires. • Students may be very detailed in their descriptions of wildfire locations. Encourage the students to focus on areas with large-scale fires. After students complete the See, Think, Wonder chart, have them transition to answering Q1 to Q5.	The students view the NASA simulation of the carbon emissions from wildfires. Based on their observations from the simulation, the students will complete a See, Think, Wonder chart. After completing the See, Think, Wonder chart, the students will answer Q1 to Q5 to demonstrate understanding of the locations that experience wildfires. Students will also use prior knowledge to predict why wildfires occur.	**25 min**

What the teacher does	What the student does	Time
• Q1 and Q2 are designed to ensure students can identify the locations that experience wildfires. • Q3 – Q5 are designed to learn about student thinking and student ideas about the causes of wildfires based on their prior knowledge. ***Assessment Opportunity #1 (Student identification of locations that experience wildfires)*** ***Assessment Opportunity #2 (Student prior knowledge about wildfires and their causes).***		
2. Have the students transition to the small-group discussion based on Q4 and Q5. • Show students the Turn & Discuss quality criteria to help students have an effective and productive discussion. Circulate the room as the students are engaging in their discussion to ensure they are properly utilizing the Turn & Discuss quality criteria. After 5 minutes, bring the students together and have three groups share their discussions about Q4 or Q5. • Encourage students to use the sentence starters from the Turn & Discuss quality criteria when linking ideas between multiple groups. ***Assessment Opportunity #3 (Student discussions about Q4 and Q5).***	The students review the Turn & Discuss quality criteria. The students take 5 minutes to discuss their answers to Q4 and Q5 with a small group. Three small groups will share their ideas with the class and will use sentence starters from the Turn & Discuss quality criteria when linking ideas between multiple groups.	**15 min**
3. Have the students individually answer Q6 – Q8. • As you circulate the room, ensure students are correctly identifying dry and hot climate as a factor for increasing wildfires. • For Q6, ensure the students are identifying the overall trend in the graph. Although the amount of wildfires can increase or decrease from year to year, the overall trend is increasing.	The students answer Q6 through Q8 to evaluate the current trend of the number of wildfires in the western United States. Students will also predict and then identify the environmental conditions that are conducive to the spread of wildfires.	**10 min**

Summary/Conclusion: The students individually answer Q6 – Q8.

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them. Students will also have access to highlighters during reading activities.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.
- Students are given sentence starters to use during class discussions.
- All images and graphs have alternative text.
- Students who need extra support can join the teacher for small group instruction and more efficient feedback.
- Students who are performing at a higher level can complete the tasks provided in the For Further Exploration part of the lesson plan.

Next Lesson: The next lesson the students will learn about the El Niño Southern Oscillation (ENSO) and how ENSO can be connected to wildfires.

For Further Exploration:

1. Go to this link to learn about NASA missions and satellites used to gather information about wildfires.
2. Go to this link to access NASA resource FIRMS (Fire Information for Resource Management Systems) to view the locations of wildfires within the last 24 hours.

Notes For Revision:

D. Supporting Documents (order according to sequence of lesson)

Anchor Phenomenon – Wildfires: Activity

Anchor Phenomenon – *The amount and intensity of wildfires has been increasing.*

Step 1. Go to the following link to view a NASA-created simulation of carbon emissions from global wildfires between 2013 and 2018.

After you watch the simulation, complete the **See, Think, Wonder** chart below.

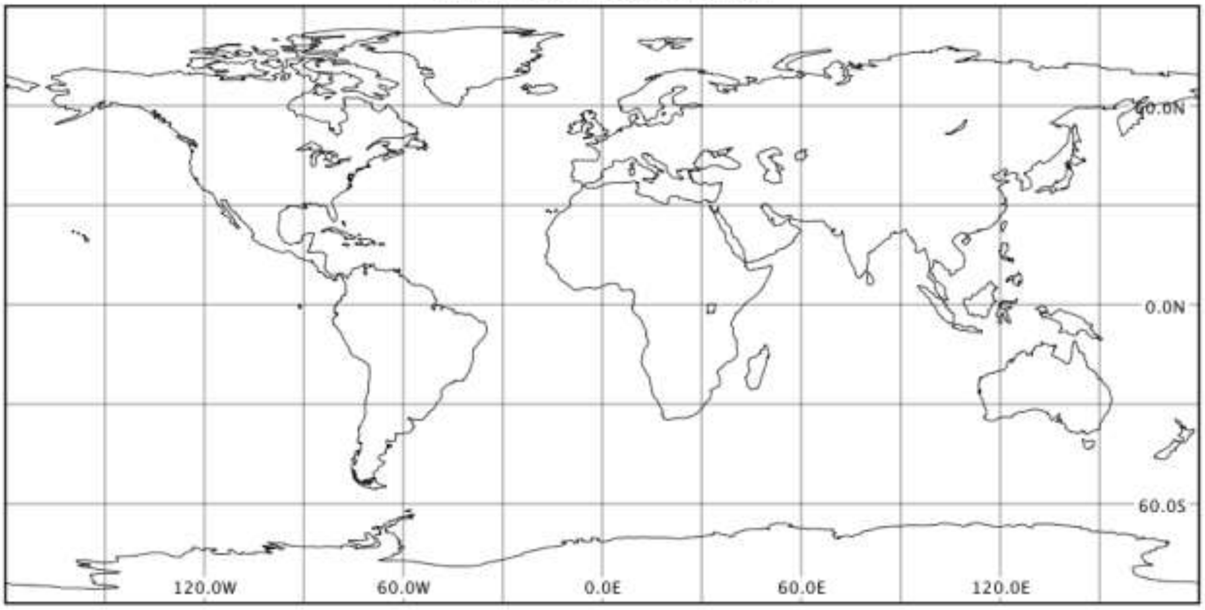
See *Write down your observations about the locations of wildfires*	**Think** *Write down what you think about the location of the wildfires*	**Wonder** *Write down what you are now wondering about the locations of wildfires*

Step 2. After completing the See, Think, Wonder chart, independently answer the following questions.

Q1. On the map below, use a red colored pencil to shade in the locations that experience wildfires each year based on the simulation.

Global Wildfires 2003 – 2018

NASA Carbon Emission Simulation



Q2. Describe the general locations that experience wildfires each year based on the simulation.

Q3. Why do you think wildfires occur each year in specific parts of the world?

Q4. How do you think wildfires are started?

Q5. Out of all the locations that experience wildfires each year, which surprised you the most? Why?

Q6. Go to this link to access a resource from the NASA Earth Observatory titled Fire. This resource contains a simulation that shows monthly locations of fires around the world. View the simulation, read the text, and answer the questions below.

a) How can wildfires start naturally?

____

b) Fires occur each year in similar locations around the world because they are intentionally set by humans. Why do humans intentionally start fires in specific regions of the world?

____

____

c) Describe two examples of locations at which fires are intentionally set by humans. Include information about when the fires are set.

Location #1: ____

____

Location #2: ____

____

Answer Q7 and Q8 based on the following link. Go to this link to access a NASA article titled Satellite Data Record Shows Climate Change's Impact on Fires.

Q7. Wildfires can result from both natural and human causes. Despite the causes, specific environmental conditions set the stage for wildfires. Identify two environmental conditions that are likely to lead to wildfires.

____

____

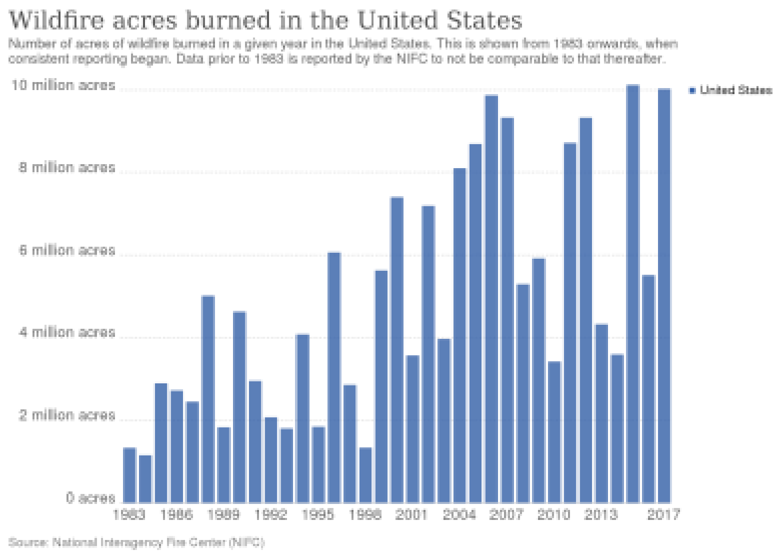
Q8. In addition to the destruction of land and polluting the atmosphere, describe two impacts wildfires can have on humans and the environment.

(1) ____

(2) ____

Step 3. Engage in a 10-minute Turn & Discuss with your group members to **discuss the following prompt.**

Although wildfires can begin by accident due to human error, fires can occur naturally and from human intent. Despite the cause, number of wildfires and the amount of land burned has been increasing in locations around the world, such as the Western United States. The graph below from the* National Interagency Fire Center *shows that the amount of land burned by wildfires in the Western United States has generally increased from 1983 to 2017.



Discuss with your group how you believe climate change has influenced the number of wildfires, locations experiencing wildfires, and the impacts of wildfires. Then, discuss how wildfires and their impacts will be affected by climate change in the future.

Set a 10-minute timer to ensure your group remains on task. To help guide your discussion, review the following Turn & Discuss Quality Criteria. Must-haves are components that need to be included in your discussion, while Amazings are components that will elevate your discussion.

Turn & Discuss Quality Criteria

Must-Haves	Amazings
• Stay on task • All students contribute by either speaking or actively listening to group members • All students can represent ideas of the group after the discussion • Students use sentence starters: *I agree/disagree with ___________ because…* *I would like to go back to what ________ said about __________.*	• Students open up the discussion to other groups • Discussion leads to another BIG IDEA question • Students use content-related vocabulary • Students make connections to previously learned concepts

Answers - Anchor Phenomenon - Wildfires

Anchor Phenomenon – *The amount and intensity of wildfires has been increasing.*

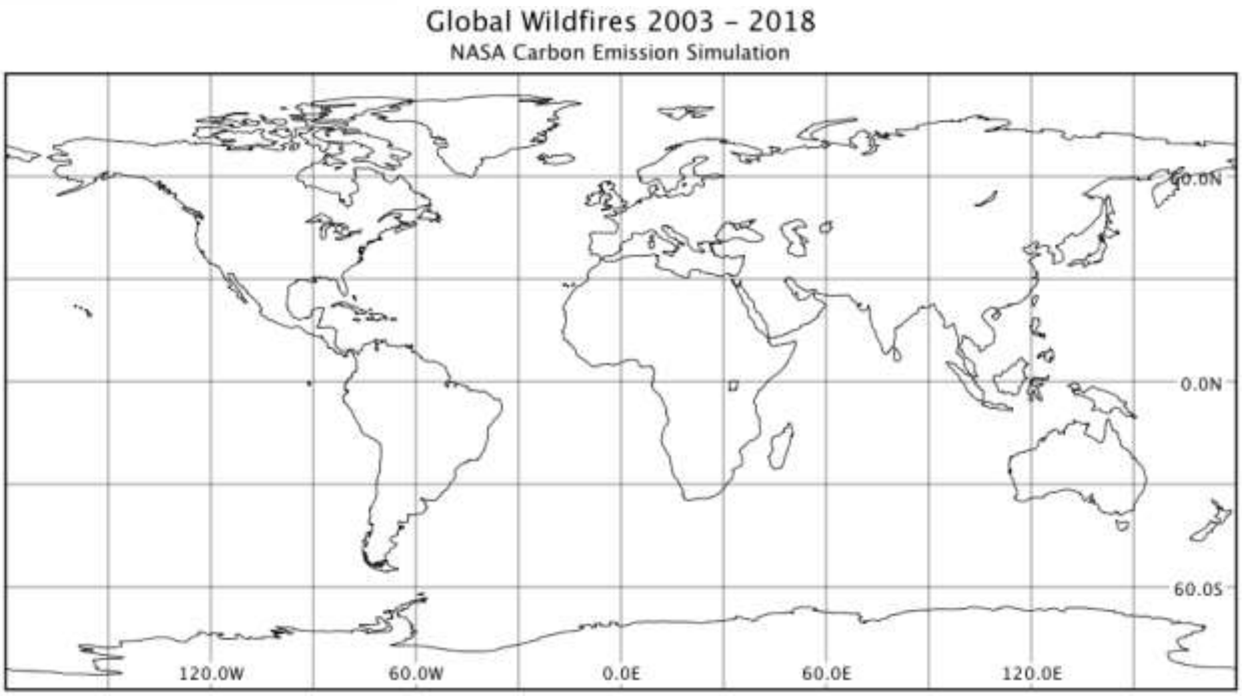
Step 1. Go to the following link to view a NASA-created simulation of carbon emissions from global wildfires between 2013 and 2018.

After you watch the simulation, complete the **See, Think, Wonder** chart below.

See *Write down your observations about the locations of wildfires*	**Think** *Write down what you think about the location of the wildfires*	**Wonder** *Write down what you are now wondering about the locations of wildfires*

Step 2. After completing the See, Think, Wonder chart, independently answer the following questions.

Q1. On the map below, use a red colored pencil to shade in the locations that experience wildfires each year based on the simulation.



Q2. Describe the general locations that experience wildfires each year based on the simulation.

Northwest coast of South America (Brazil), central to southern Africa, and northern Australia.

Q3. Why do you think wildfires occur each year in specific parts of the world?

Wildfires occur each year in specific parts of the world due to the hot and dry climate.

Q4. How do you think wildfires are started?

Wildfires can be started naturally by lightning strikes, or caused by humans due to deforestation processes, overgrown campfires, cigarettes, etc.

Q5. Out of all the locations that experience wildfires each year, which surprised you the most? Why?

Answers will vary, but the answer that will stand out is Alaska. Many students believe Alaska is mostly snow and ice and therefore does not have an environment conducive to wildfires.

Q6. Go to this link to access a resource from the NASA Earth Observatory titled Fire. This resource contains a simulation that shows monthly locations of fires around the world. View the simulation, read the text, and answer the questions below.

a) How can wildfires start naturally?

Wildfires can start naturally due to lightning strikes.

b) Fires occur each year in similar locations around the world because they are intentionally set by humans. Why do humans intentionally start fires in specific regions of the world?

Humans intentionally start fires to manage farmland and to clear vegetation for farming. Fires can clear dead and dying brush to help restore ecosystems.

c) Describe two examples of locations at which fires are intentionally set by humans. Include information about when the fires are set.

Location #1: **Humans intentionally burn land for agriculture in Africa from the north to the south during the dry season.**

Location #2: **Humans also burn land during late winter/early spring in Southeast Asia.**

Answer Q7 and Q8 based on the following link. Go to this link to access a NASA article titled Satellite Data Record Shows Climate Change's Impact on Fires.

Q7. Wildfires can result from both natural and human causes. Despite the causes, specific environmental conditions set the stage for wildfires. Identify two environmental conditions that are likely to lead to wildfires.

The two environmental conditions likely to lead to wildfires are a hot and dry climate.

Q8. In addition to the destruction of land and polluting the atmosphere, describe two impacts wildfires can have on humans and the environment.

(1) **Smoke is a health hazard to humans as the soot enters the lungs and can cause respiratory problems**

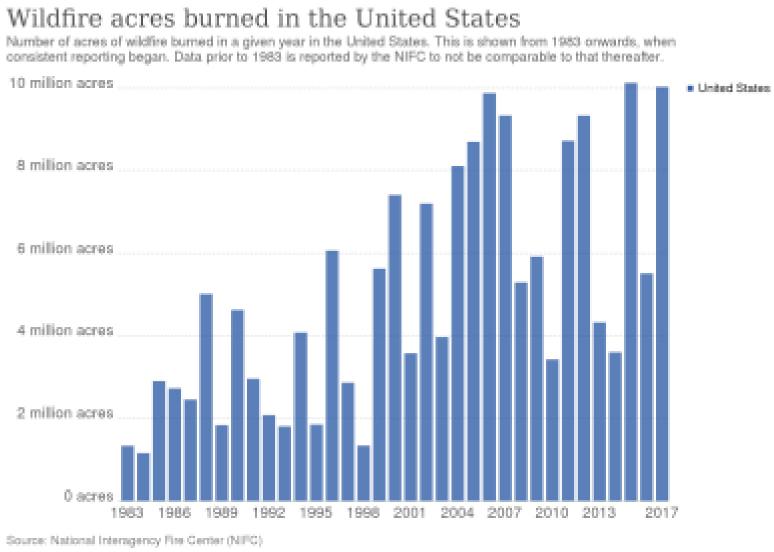
(2) **Air quality for individuals downwind of the fires can be reduced**

(3) **Fires can threaten water quality**

(4) **The reduction of vegetation due to fires can increase the threat of erosion and mudslides.**

Step 3. Engage in a 10-minute Turn & Discuss with your group members to **discuss the following prompt.**

Although wildfires can begin by accident due to human error, fires can occur naturally and from human intent. Despite the cause, number of wildfires and the amount of land burned has been increasing in locations around the world, such as the Western United States. The graph below from the National Interagency Fire Center ***shows that the amount of land burned by wildfires in the Western United States has generally increased from 1983 to 2017.***



Discuss with your group how you believe climate change has influenced the number of wildfires, locations experiencing wildfires, and the impacts of wildfires. Then, discuss how wildfires and their impacts will be affected by climate change in the future.

Set a 10-minute timer to ensure your group remains on task. To help guide your discussion, review the following Turn & Discuss Quality Criteria. Must-haves are components that need to be included in your discussion, while Amazings are components that will elevate your discussion.

Turn & Discuss Quality Criteria

Must-Haves	Amazings
• Stay on task • All students contribute by either speaking or actively listening to group members • All students can represent ideas of the group after the discussion • Students use sentence starters: *I agree/disagree with ____________ because…* *I would like to go back to what _________ said about __________.*	• Students open up the discussion to other groups • Discussion leads to another BIG IDEA question • Students use content-related vocabulary • Students make connections to previously learned concepts

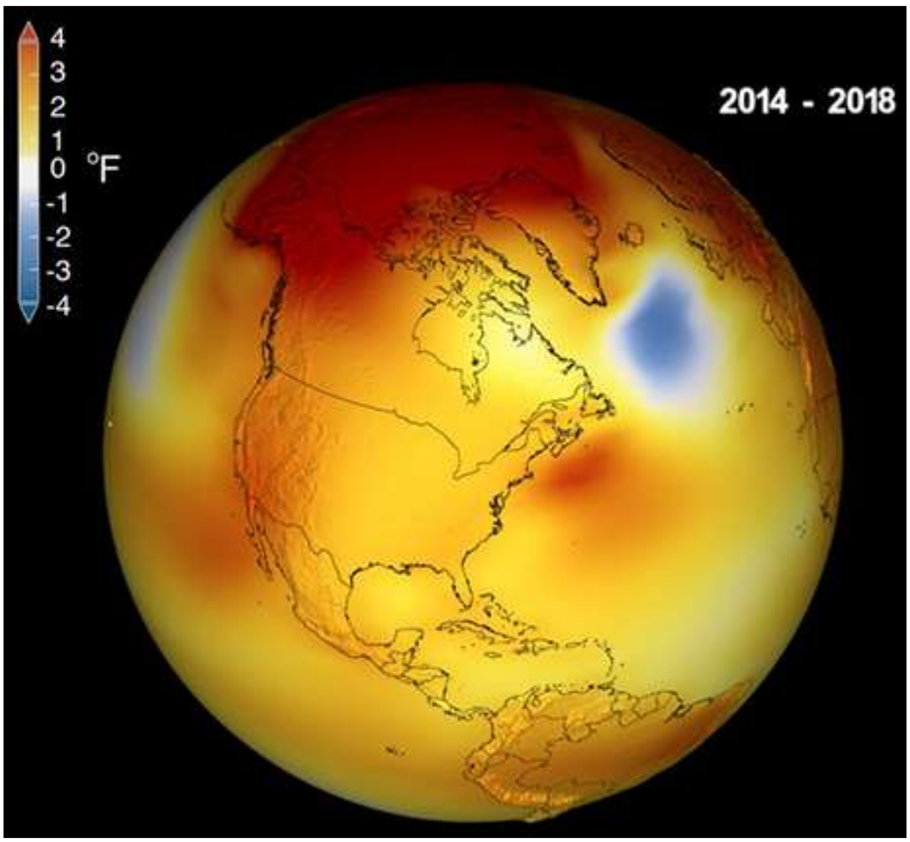
E. Conclusion and overview of linkages to next lesson and unit goals

In this lesson the students received an introduction to the anchor phenomenon of the unit. The students were able to observe the common locations of wildfires around the world and discuss the possible causes of wildfires and any ideas that were surprising to them. At the end of the lesson the students were able to identify the environmental conditions that are most favorable to the development and spread of wildfires. The underlying theme of wildfires in this lesson will be connected to the themes of the next four lessons. The students will learn how natural and human-induced changes in climate can lead to wildfires around the world. In the next lesson, the students will learn about the El Niño Southern Oscillation (ENSO) and how the different phases of ENSO can lead to wildfires.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Changes in Climate & Wildfires
Lesson #2 Title: El Niño Southern Oscillation
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



IX. Lesson #2: El Niño Southern Oscillation

A. Summary and Goals of Lesson

The goal of this lesson is to teach the students how and why different phases of the El Niño Southern Oscillation (ENSO) can change temperature and precipitation patterns around the world. This **5E**-structured lesson is based on the following investigative phenomenon:

The El Niño Southern Oscillation (ENSO) can influence global climate patterns.

The lesson begins with the **Engage** activity in which the students watch a NASA simulation of the development of the 2015 El Niño event and generate three questions they have about El Niño. The students will then share their questions with a small group and discuss possible answers to their questions. The students will also use a map showing sea surface temperature anomalies during El Niño conditions to make predictions about how precipitation in four different regions will be impacted.

During the **Explore** activity, the students will use NASA's Panoply software to read and display sea surface temperature anomaly data and precipitation anomaly data. The students will first explore how sea surface temperature anomalies change in the equatorial Pacific Ocean during the El Niño and La Niña phases of ENSO. The goal is for the students to define El Niño and La Niña events based on the sea surface temperature anomalies. The students will then explore the precipitation anomaly data to uncover how El Niño and La Niña events change precipitation patterns in different regions around the world.

During the **Explain** activity, the students will explain how and why different phases of ENSO occur and result in changes to sea surface temperature anomalies. The students will investigate an ENSO simulation from Prentice Hall to learn how changes in surface ocean currents, wind patterns, and air pressure lead to the sea surface temperature anomalies and precipitation anomalies identified in the Explore activity.

During the **Elaborate** activity, the students will make connections between the 2015 – 2016 ENSO event and the wildfires in the Amazon. The students will use Panoply to interpret the sea surface temperature anomaly data and precipitation anomaly data during that time to explain how changes in climate led to the development of the wildfires.

Finally, during the **Evaluate** activity, the students will answer five assessment questions based on ENSO and the impact on global climate.

B. Table of Contents for lesson

C. 5 E Lesson Model Template

5E Lesson Plan - Earth Science

Unit: Changes in Climate & Wildfires **Topic**: El Niño Southern Oscillation (ENSO)

Prior Learning:

The following Next Generation Science Standards (NGSS) Performance Expectations (PE), Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEP), and Cross-Cutting Concepts (CCC) should have been experienced by the students in Middle School:

- **PE**: MS-ESS2-5
    - **DCI**: ESS2.C - The Role of Water in Earth's Surface Processes & ESS2.D - Weather and Climate
    - **SEP**: Planning and Carrying Out Investigations
    - **CCC**: Cause and Effect
- **PE**: MS-ESS2-6
    - **DCI**: ESS2.D - Weather and Climate
    - **SEP**: Developing and Using Models
    - **CCC**: Systems & Systems Models

In this lesson, the students will use the 5E lesson structure to learn about the El Niño Southern Oscillation (ENSO) and how the warm (El Niño) and cold (La Niña) phases of ENSO lead to changes in global precipitation patterns. Specifically, students will be exploring the following **investigative phenomenon:**

The El Niño Southern Oscillation (ENSO) can influence global climate patterns

Students will build on their knowledge of prior learning in Middle School by investigating how changes to the ocean system can lead to changes in the atmosphere, ultimately leading to widespread changes in climate. The students should have prior knowledge of ocean currents, wind circulation, and how atmospheric pressure influences the amount of precipitation for a given location. For example, students should understand that low-pressure systems can lead to precipitation, while high-pressure systems reduce precipitation. Additionally, students should have knowledge from the previous Anchor Phenomenon activity about the environmental conditions that lead to wildfires. Students will make further connections between ENSO-related changes in climate and wildfires towards the end of the lesson.

Aim: How does the El Niño Southern Oscillation (ENSO) influence global climate patterns?

Next Generation Science Standards (NGSS):

Performance Expectation:

- **HS-ESS2-2**. – Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to Earth's systems.
    - **Science and Engineering Practices:**
        - Analyzing and Interpreting Data
    - **Disciplinary Core Ideas**:
        - ESS2.D: Weather and Climate

- **Cross-cutting Concepts:**
  - Stability and Change

Performance Expectation:

- **HS-ESS2-4.** – Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate
  - **Science and Engineering Practices:**
    - Analyzing and Interpreting Data
  - **Disciplinary Core Ideas**:
    - ESS2.D: Weather and Climate
  - **Cross-cutting Concepts:**
    - Cause and Effect

Multiple Science Domains:
This lesson contains links between the Earth and Space Science DCIs listed above and the following Physical Science DCIs:

- PS3.B Conversion of Energy and Energy Transfer
- PS4.B Electromagnetic Radiation

Common Core Learning Standards (CCLS):

- **11-12.RST.3** - Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

- **11-12.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

- **11-12.RST.9** - Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Performance Objective: Students will be able to investigate the warm (El Niño) and cold (La Niña) phases of the El Niño Southern Oscillation (ENSO) and their impacts on global precipitation by analyzing sea surface temperature anomaly and precipitation anomaly data in NASA's Panoply software.

Students will be able to explain why ENSO has warm and cold phases by exploring an ENSO animation and relating the effects illustrated in the animation to the sea surface temperature anomaly and precipitation anomaly data analyzed in Panoply.

Materials:

- Class set of computers
- NASA Panoply software (download instructions are included after lesson plan).

Links to electronic resources are provided below:

- Link to NASA GISS Panoply software

- Link to NASA simulation showing the development of the 2015 El Niño
- Link to the Smith & Reynolds Extended Reconstructed Sea Surface Temperature Anomaly data
- Link to the Global Precipitation Climatology Project average monthly precipitation and average long-term monthly precipitation data from NOAA/OAR/ESRL PSL, Boulder, Colorado, USA.
- Link to El Niño Southern Oscillation simulation from Prentice Hall
- Link to NASA article titled El Niño Could Drive Intense Season for Amazon Fires
- Link to NASA-sponsored GLOBE resource about ENSO

Vocabulary:

- El Niño Southern Oscillation (ENSO)
- El Niño
- La Niña
- Anomaly

Development of the 5E Lesson: Approximate Four-Day Lesson (Four 50-minute periods).

What the teacher does	What the student does	Time
1. ENGAGE Introduce the students to the ENGAGE activity by having them first access this link to the NASA simulation of the 2015 El Niño event. Circulate the room as the students view the simulation of the 2015 El Niño event and generate three questions they have about El Niño. As the students are engaging in the Turn & Discuss activity with their group members, circulate to ensure all students are following the Turn & Discuss Quality Criteria. While students are answer Q1 of the activity, remember to not give any answers away. This part of the activity should be based only on student prior knowledge and experiences. ***Assessment Opportunity #1 (Student discussions about El Niño and predictions about impacts on precipitation).***	The students complete the ENGAGE activity for a brief introduction to El Niño. The students will view a simulation of the development of the 2015 El Niño event and generate three questions they have about El Niño. Students will take 5 minutes to engage in a Turn & Discuss with a small group. The students will read their questions aloud and the group will identify common questions and any questions that sparked interest within the group. Any remaining time will be used for the students to attempt to answer the common/intriguing questions. The students will finish the ENGAGE activity by predicting how an El Niño event can impact precipitation in different regions around the world.	**20 min**
2. EXPLORE – Part 1: Sea Surface Temperature Anomaly	The students will demonstrate an understanding of the meaning of the term "anomaly".	**50 min**

<table>
<tr><th>What the teacher does</th><th>What the student does</th><th>Time</th></tr>
<tr><td>Complete Q1 and Q2 with the students to ensure they have a strong understanding of the meaning of an anomaly.

Ensure that all students are able to download the sea surface temperature anomaly data and that they can open the data in Panoply.

Circulate the room as the students complete Part 1: Sea Surface Temperature Anomaly.
Pay special attention to how the students explain the meaning of sea surface temperature anomalies. A positive anomaly does not mean the water is hot, but rather warmer than average.
Assessment Opportunity #2 (Student answers to the Explore Part 1 questions)</td><td>The students will download average monthly sea surface temperature anomaly data and analyze the data in Panoply. Students will investigate different dates that represent El Niño and La Niña events to ultimately identify the sea surface temperature anomalies associated with each event.

Students will use their analyses of the sea surface temperature anomaly data to define an El Niño and La Niña event.</td><td></td></tr>
<tr><td>3. EXPLORE – Part 2: Precipitation

Ensure that students are able to download the average monthly precipitation data and the average long-term monthly precipitation data.

Once the datasets are downloaded, ensure the students are correctly combining the data in Panoply to calculate the precipitation anomaly.

As the students are answering questions about the data, remind the students that they should only focus on large positive or negative precipitation anomalies.
If students are having trouble identifying the large positive and negative anomalies, encourage them to focus on regions near the equatorial Pacific region.
Assessment Opportunity #3 (Student answers to the Explore Part 2 questions)</td><td>The students will download the average monthly precipitation data and the average long-term monthly precipitation data.

The students will use Panoply to combine the two precipitation datasets and calculate the monthly precipitation anomaly.

The students will analyze the precipitation anomalies during El Niño and La Niña events to identify regions that experience increases and decreases in precipitation during each respective event.</td><td>50 min</td></tr>
<tr><td>4. EXPLAIN

Show students how to <u>access this link to the ENSO animation that shows the normal phase, El Niño, and La Niña.</u></td><td>The students will use an animation that shows the normal, El Niño, and La Niña phases of ENSO to uncover how and why El Niño and La Niña events occur.</td><td>50 min</td></tr>
</table>

What the teacher does	What the student does	Time
Circulate the room as the students are completing the EXPLAIN activity. • Check in with students to ensure they are accurately answering Q15 and Q16. These two questions are the most important as they allow students to demonstrate their understanding of how El Niño and La Niña events occur. If more information about ENSO for the students is needed, access this link to the NASA Earth Observatory. ***Assessment Opportunity #4 (Student answers to the Q15 and Q16 of the EXPLAIN activity).***	The students use the information gathered from Q1 to Q14 of the EXPLAIN activity to answer Q15 and Q16 to summarize how El Niño and La Niña events develop, respectively.	
5. ELABORATE Read the ELABORATE task aloud to the students. Circulate as the students are investigating the cause of the 2016 wildfires in the Amazon. • Make sure the students are using the precipitation anomaly data from the combined precip.nc and precip_ltm.nc datasets. For information about how ENSO influenced wildfires in the Amazon in 2016, access this link to NASA article. ***Assessment Opportunity #5 (Student answers to the ELABORATE task).***	The students read the prompt to the ELABROATE task. The students use the sea surface temperature anomaly and precipitation anomaly data to investigate how ENSO influenced the 2016 wildfire outbreak in the Amazon during the dry season.	**30 min**
6. EVALUATE Circulate as the students answer the EVALUATE questions. The questions are from previous New York State Earth Science Regents exams. ***Assessment Opportunity #7 (Student answers to the EVALUATE questions).***	The students answer the EVALUATE questions from the NYS Earth Science Regents exam.	**5 min**

Summary/Conclusion: The students answer the EVALUATE questions from the NYS Earth Science Regents exam.

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them. Students will also have access to highlighters during reading activities.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.
- Students are given sentence starters to use during class discussions.
- All images and graphs have alternative text.
- Students who need extra support can join the teacher for small group instruction and more efficient feedback.
- Students who are performing at a higher level can complete the tasks provided in the For Further Exploration part of the lesson plan.
- Students with a visual impairment can receive additional guidance from a sighted teacher about the color schemes in temperature and precipitation-based maps. Additionally, students have the freedom to choose a color scale in Panoply to suit their visual needs when evaluating the sea surface temperature and precipitation anomalies.

Next Lesson: The next lesson the students will learn about modern-day changes in global temperature through NASA's GISTEMP surface temperature anomaly data. Students will identify the regions most impacted by increasing temperature and develop an explanation for why these regions are experiencing the greatest rise in temperature. Students will also be able to identify and explain Arctic amplification and make connections to recent wildfires in the Arctic.

For Further Exploration:

1. Go to this link to learn about NASA missions and satellites used to gather information about wildfires.
2. Go to this link to access NASA resource FIRMS (Fire Information for Resource Management Systems) to view the locations of wildfires within the last 24 hours.

Documents in Lesson Plan in Order of Appearance:

1. Panoply Download Instructions
2. ENSO & Wildfires Activity
3. ENSO & Wildfires Answers

D. Supporting Documents (order according to sequence of lesson)

NASA GISS Panoply Download Instructions for macOS

Step 1. Make sure that the computer on which Panoply will be downloaded has a current version of Java.

Step 2. [Go to this link to access NASA's Panoply software]() and click on the option to download Panoply for macOS, as shown below.

Panoply Data Viewer

Download Panoply

Panoply requires a computer with **Java 9** (or later version) installed.

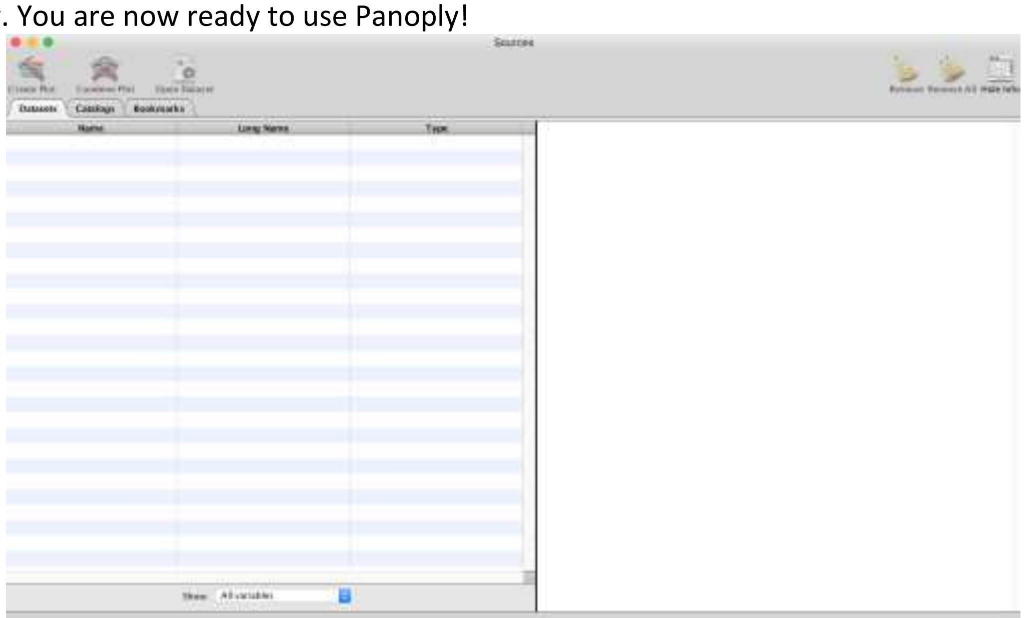
The current version of Panoply is 4.12.3, released 2021-01-25.

- Download Panoply 4.12.3 for **macOS**, 36 MB DMG, uses native filechooser
- Download Panoply 4.12.3 for **macOS** (JFC), 36 MB DMG, uses Java filechooser
- Download Panoply 4.12.3 for **Windows**, 33 MB ZIP
- Download Panoply 4.12.3 "generic" for **Linux**, etc., 32 MB ZIP
- Download Panoply 4.12.3 "generic" for **Linux**, etc., 32 MB TGZ
- View checksums: [MD5] [SHA1] [SHA256]

Step 3. Once Panoply is done downloading, double-click the Panoply.dmg located on the Desktop. Then drag the Panoply application to where you keep applications, probably either your user Applications folder or else the system-wide Applications folder.

Step 4. To run Panoply on macOS, just double-click on the Panoply application.

Step 5. A window will pop-up that allows you to choose a dataset to open in Panoply. Since we do not have a dataset to analyze just yet, you can close out that window and then the Panoply Sources window will appear as shown below. You are now ready to use Panoply!

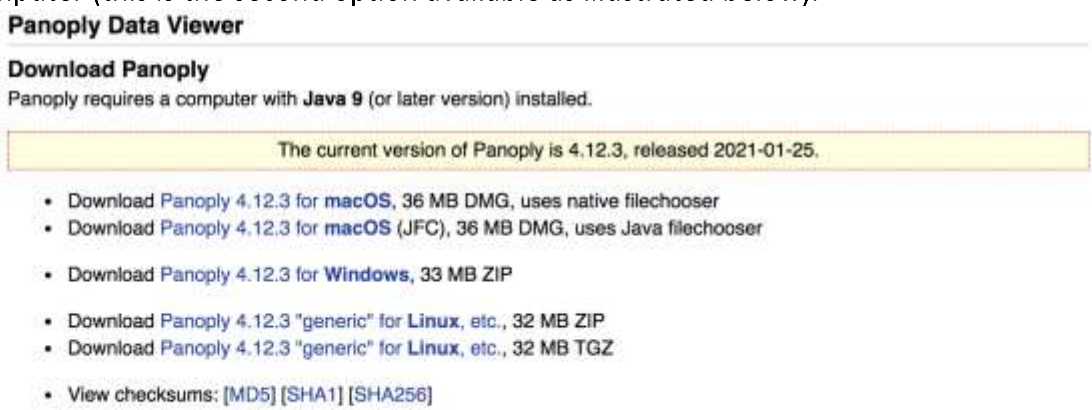


National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA GISS Panoply Download Instructions for Windows

Step 1. Make sure that the computer on which Panoply will be downloaded has a current version of Java.

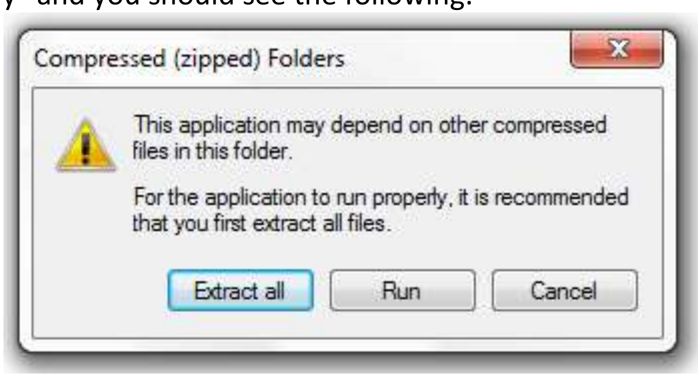
Step 2. Go to this link to access NASA's Panoply software and click on the option to download Panoply for a Windows computer (this is the second option available as illustrated below).



Step 3. Once the program is downloaded, double click on the on the folder titled "PanoplyWin".

Step 4. You should now see the following:

The "jars" folder needs to remain in this location in order for the Panoply program to work after download. Now double click on "Panoply" and you should see the following:

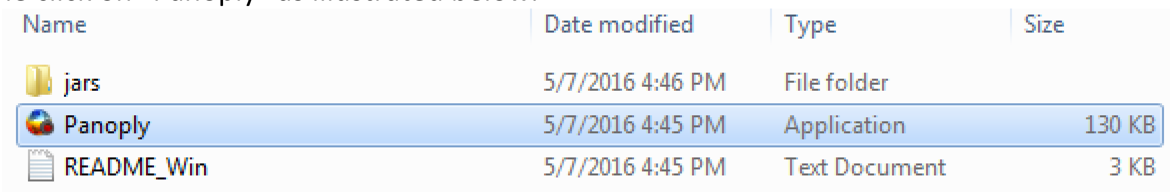


Click on "Extract all".

Step 5. You will be prompted to select a destination to extract the files to. Input the path of the destination in which you want Panoply to be installed and then click "extract".

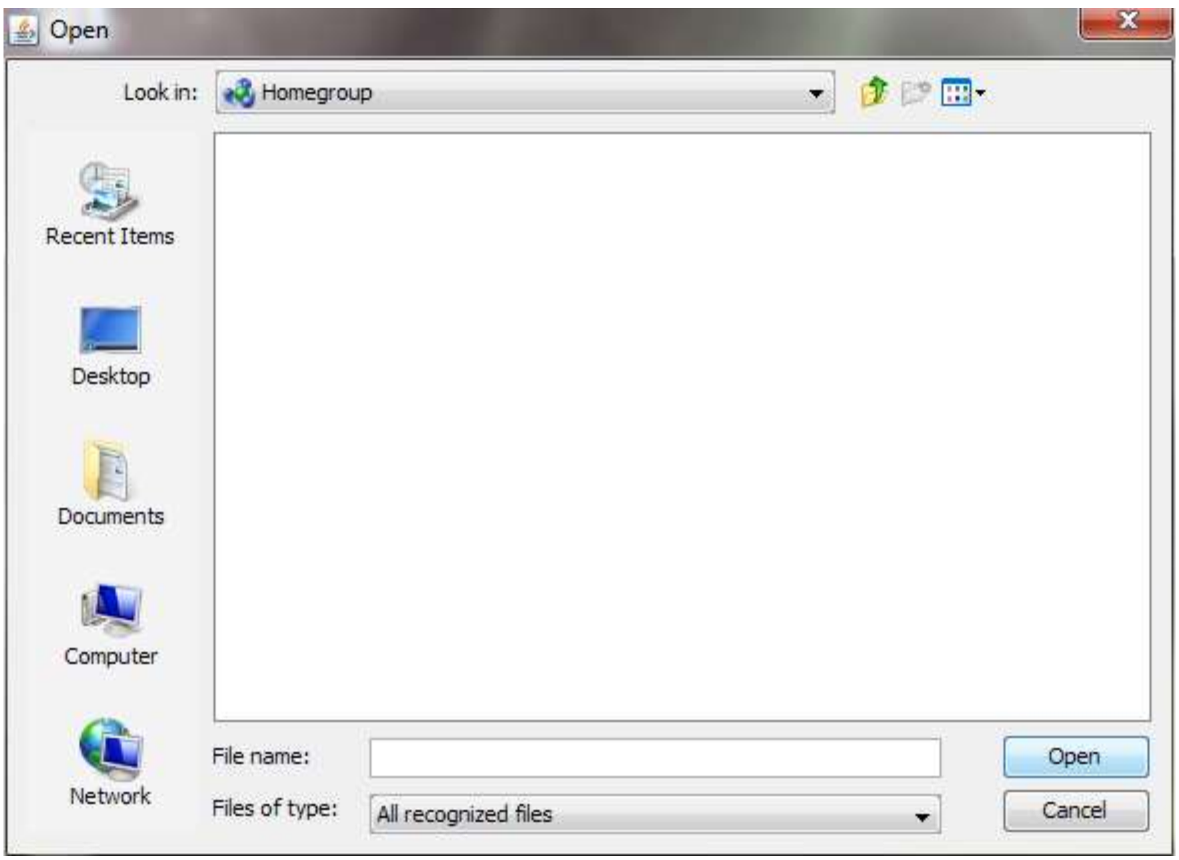
Step 6. Panoply should now be installed in the location of the destination path you designated in Step #5.

Step 7. Once you are in the location in which Panoply was installed, click on the folder titled "PanoplyWin" and then double click on "Panoply" as illustrated below.

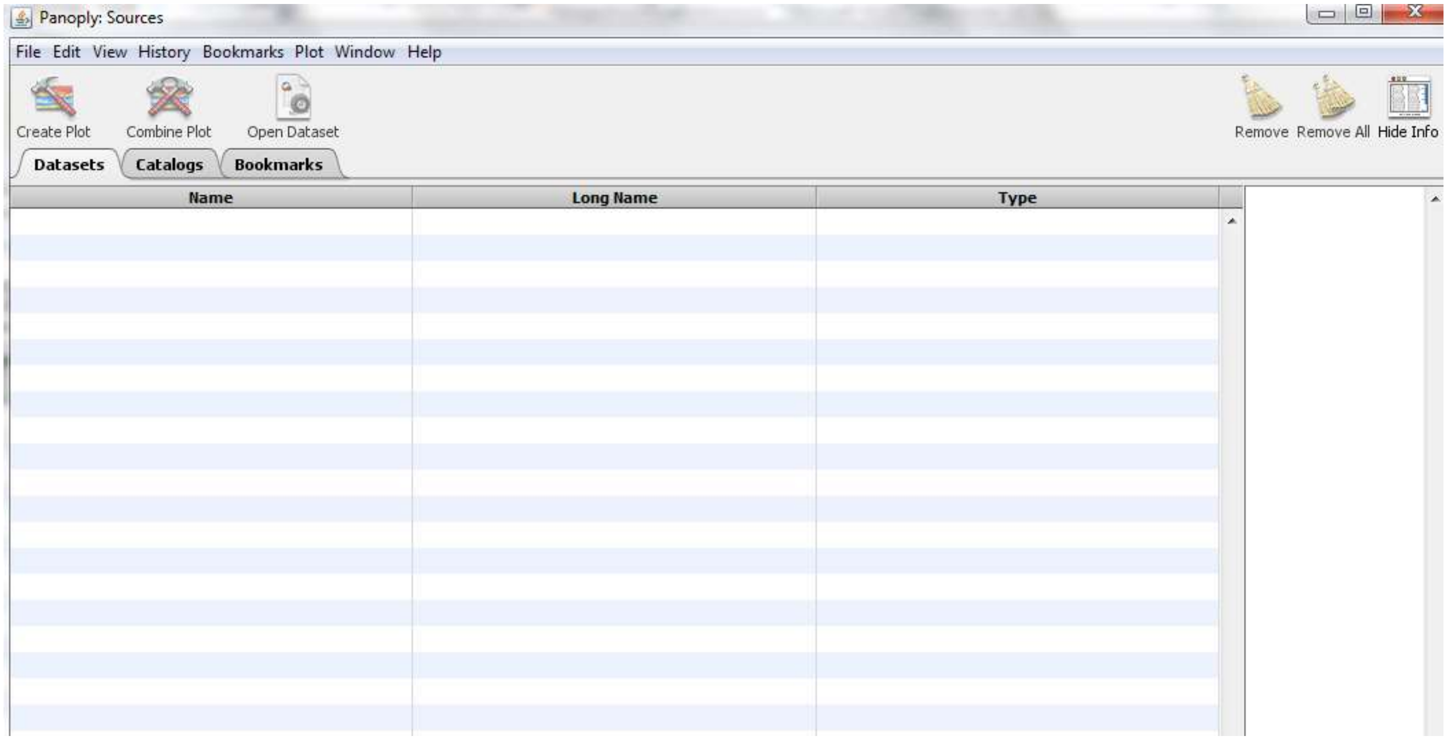


Step 8. When prompted, click "run" to start Panoply.

Step 9. If you do not see any new windows pop-up, minimize all open programs and browsers to get to your desktop. You should then see window with the Java emblem in the top left corner as shown below.



Step 10. Click "Open" and you will see the following screen:



You are now ready to use Panoply!

ENSO & Wildfires - Activity

Investigative Phenomenon – The El Niño Southern Oscillation (ENSO) can influence global climate patterns.

ENGAGE

Step 1. This is the link to a video about the development of the 2015 El Niño event. Click the link to view the simulation. After viewing the simulation, individually generate three questions you have about the development of the 2015 El Niño event in the space below.

Questions:

A. ____

____

B. ____

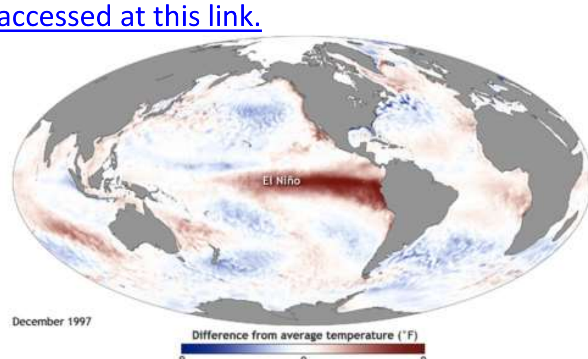
____

C. ____

____

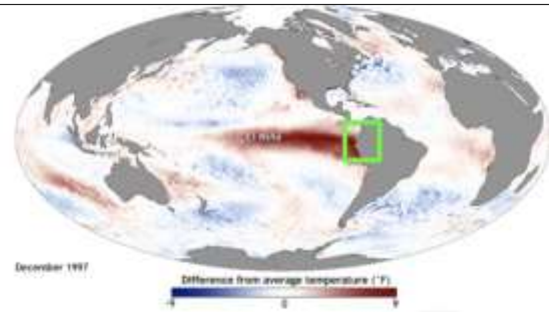
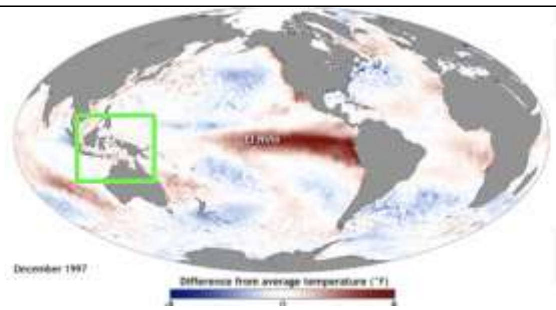
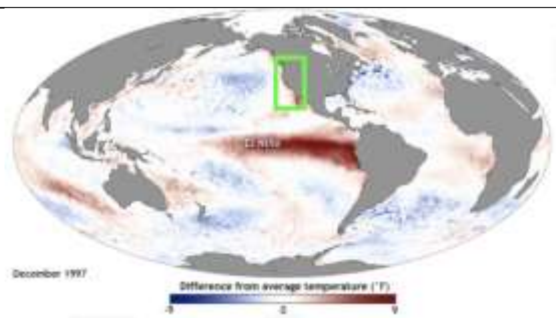
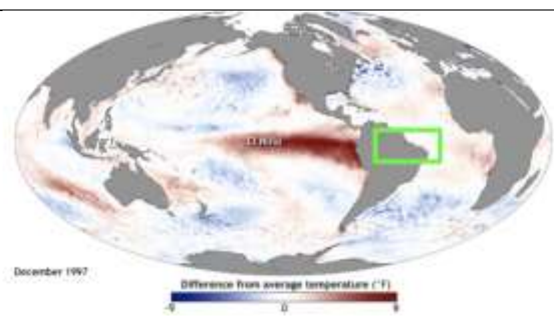
Step 2. With your group, set a timer for 5 minutes. Then, each group member will share the three questions generated. After all group members share, put a star next to any question that was repeated more than once, as well as any question that sparked an interest within the group. Use the remaining time to answer any starred questions based on your prior knowledge and experiences. Use the Turn & Discuss Quality Criteria to guide your discussion.

Step 3. The image below shows sea surface temperatures during an El Niño event. The red colors represent sea surface temperature values that are warmer than normal, which is the meaning of an El Niño event. The greatest above normal temperatures are in the eastern equatorial Pacific Ocean, off of the northwest coast of South America. The map can be accessed at this link.



National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Q1. El Niño events and the warming of water occur in the eastern equatorial Pacific Ocean but can impact the precipitation patterns of locations around the world. For each general location in the data table below, identify how you think the amount of precipitation will be impacted. Then, explain your thinking.

Location	Map	Impact on Precipitation (Increase or Decrease)
West coast of South America		**Impact**: ______________________ **Explanation**: __________________ ______________________________ ______________________________ ______________________________
Southeast Asia and Australia		**Impact**: ______________________ **Explanation**: __________________ ______________________________ ______________________________ ______________________________
West Coast of North America		**Impact**: ______________________ **Explanation**: __________________ ______________________________ ______________________________ ______________________________
East Coast of South America		**Impact**: ______________________ **Explanation**: __________________ ______________________________ ______________________________ ______________________________

EXPLORE – Part 1: Sea Surface Temperature Anomaly

Step 1. To explore different El Niño events and other phases of ENSO, we will investigate sea surface temperature anomaly data. An anomaly describes how far above or below a value is from the average. For example, a sea surface temperature anomaly describes how far above or below a value is from the average sea surface temperature.

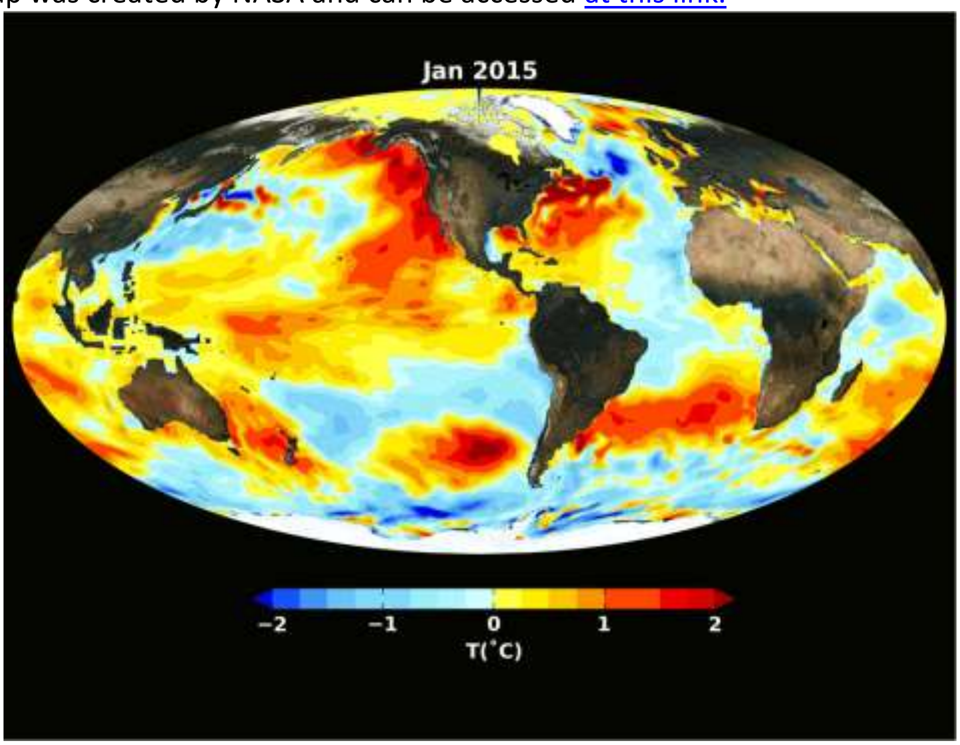
Q1. If the sea surface temperature anomaly for a location in the Atlantic was -4˚C, it does not mean the sea surface temperature was -4˚C. A temperature anomaly of -4˚C means the sea surface temperature that day was 4 degrees below (cooler than) the average temperature.

Based on this information, what would a sea surface temperature anomaly of 1˚C mean for a location in the Atlantic Ocean?

____

____

Step 2. Negative anomalies indicate values that are below average, while positive anomalies indicate values that are above average. The map below shows global sea surface temperature anomalies from January 2005. The blue colors represent negative anomalies, while the yellow, orange, and red colors represent positive anomalies. The map was created by NASA and can be accessed at this link.



Q2. Identify whether the west coast of North America experienced a positive or negative sea surface temperature anomaly in January 2005. Then, explain what the anomaly means for sea surface temperature in that region.

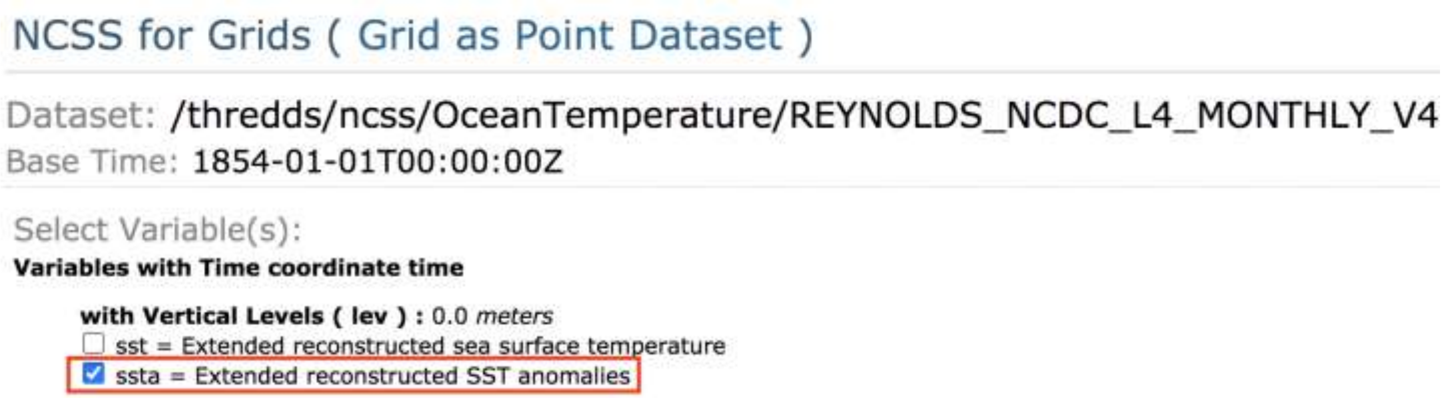
Anomaly: ___________________________________

Explanation: ____

____

Step 3. [Go to this link to access global monthly sea surface temperature anomaly data].

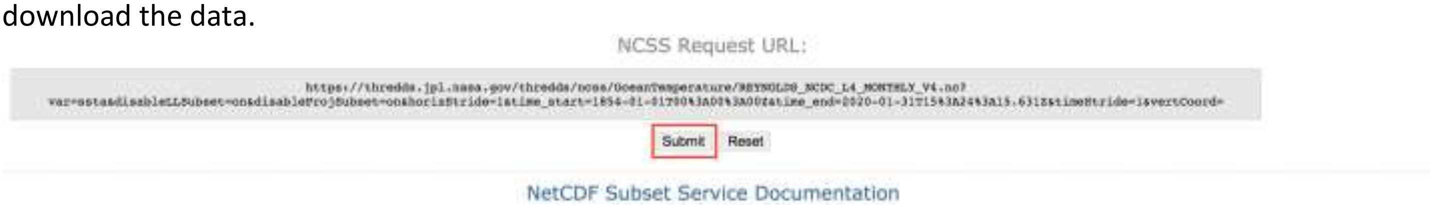
Step 4. Near the top left side of the page, locate "Select Variable(s)". Then, check the box for **ssta**, as shown in the image below.



Step 5. The right side of the page contains settings to change the location area of the data and the time range of the data. **Do not change any of the settings!**

- Since we want global sea surface temperature anomaly data, we want to download data for all latitude and longitude coordinates.
- We also want to download all monthly data from January 1854 to the most up to date month and year. At the time this activity was created, the most up to date month and year was January 2020, but this will change over time.

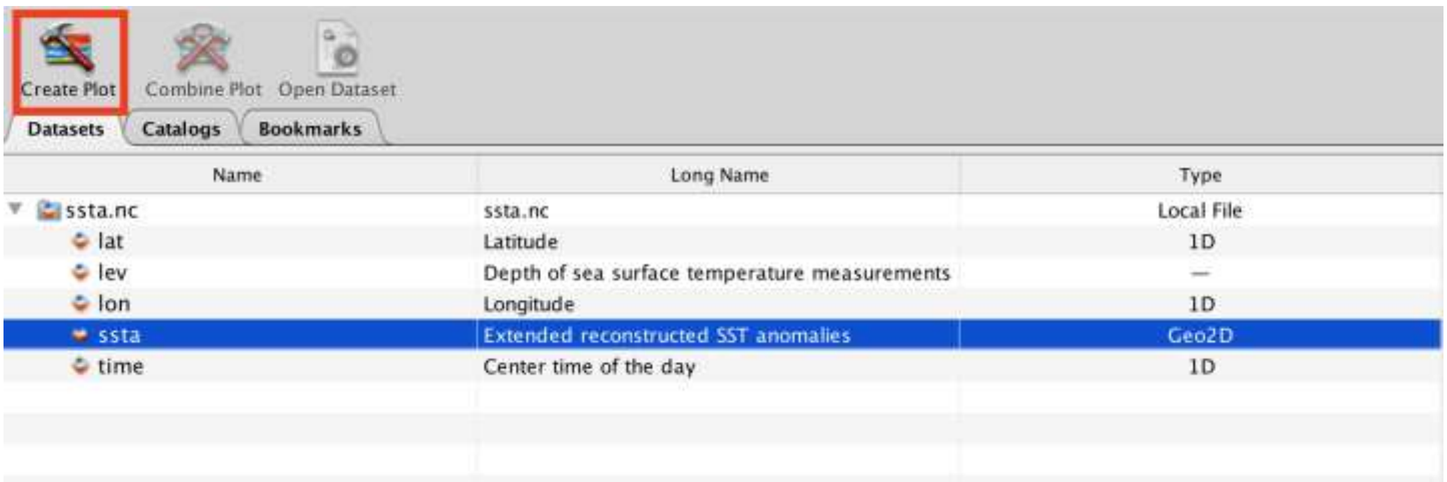
Step 6. Scroll down to the bottom of the page and click **Submit**, as shown in the image below. This will download the data.



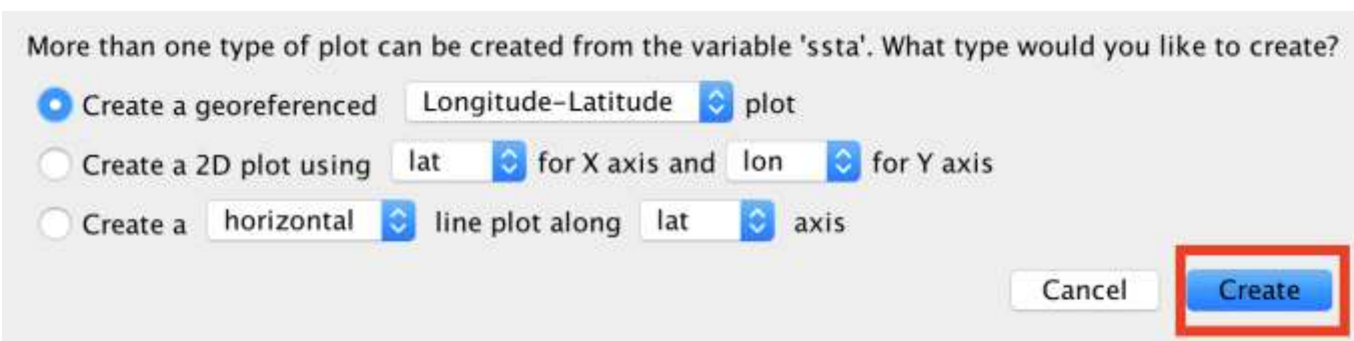
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **REYNOLDS_NCDC_L4_MONTHLY_V4.nc.** For simplicity, change the name of the file to **ssta.nc** by right-clicking on the dataset and selecting "rename".

Step 7. Open the Panoply program. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the **ssta.nc** file you saved in your downloads earlier and open it in Panoply. This dataset provides average monthly sea surface temperature anomalies for the entire Earth.

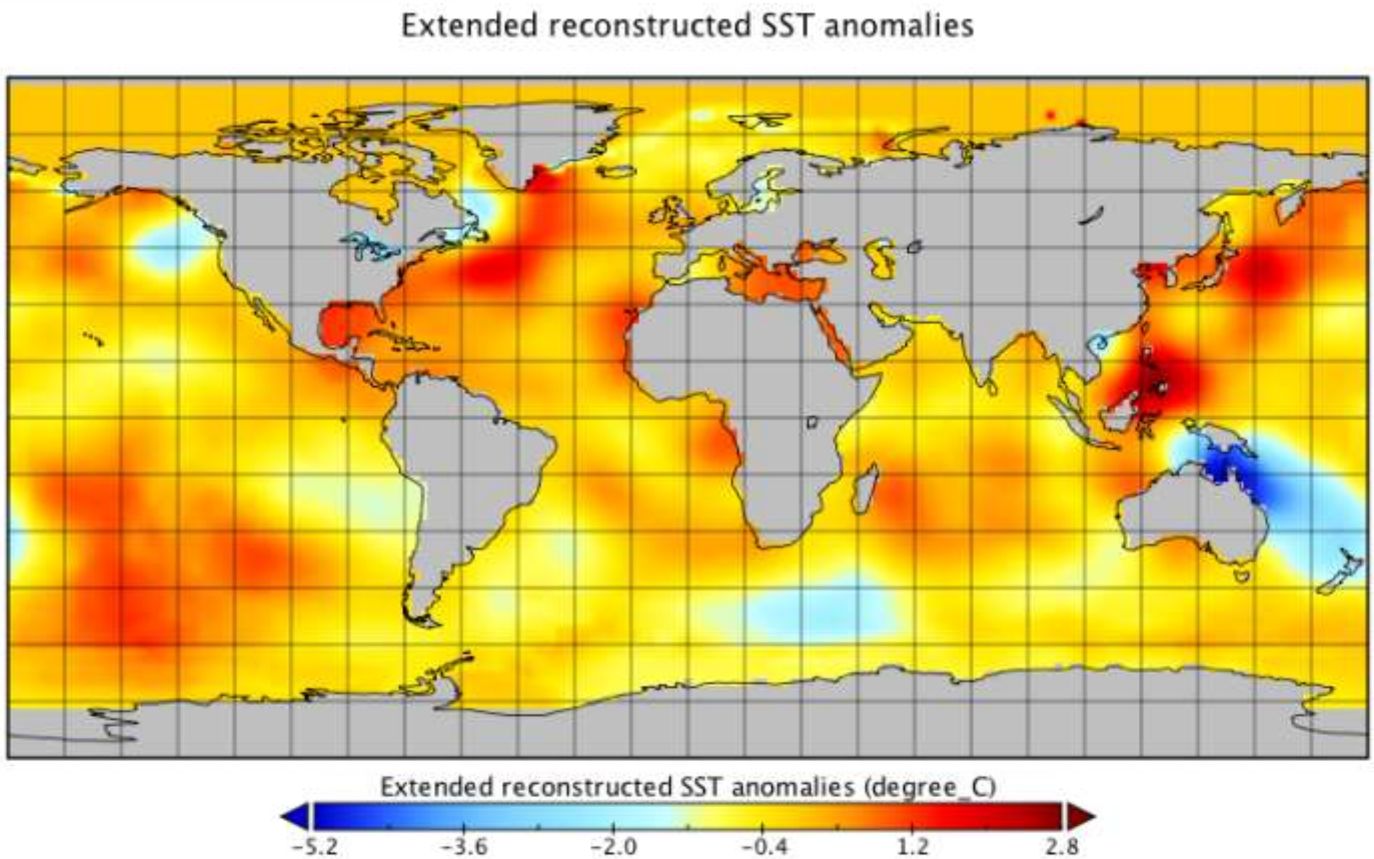
Step 8. Click on the variable titled **"ssta"** and then click **"Create Plot"** in the top left corner as shown below:



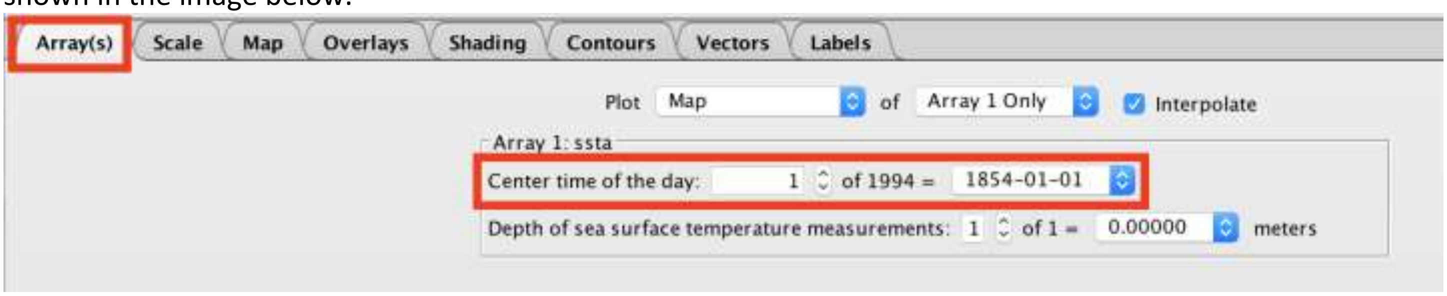
The following window will appear. Do not change any of the settings and click **"Create"** as shown below.



You should now see a map that looks like this:



Step 9. The map currently displayed is the average sea surface temperature anomaly during the month of January 1854 (1854-01-01). This can be verified by clicking on the **Array(s)** tab near the bottom of Panoply, as shown in the image below.



At the time this activity was created, the downloaded sea surface temperature anomaly data (**ssta**) contained 1,994 time slices. This means there are 1,994 months' worth of data between January 1854 and January 2020. January 1854 corresponds with time slice 1 of 1,994.

***Note:** The number of time slices could be higher if the data is downloaded after January 2020. As more monthly data is added to **ssta.nc**, the number of time slices will increase.

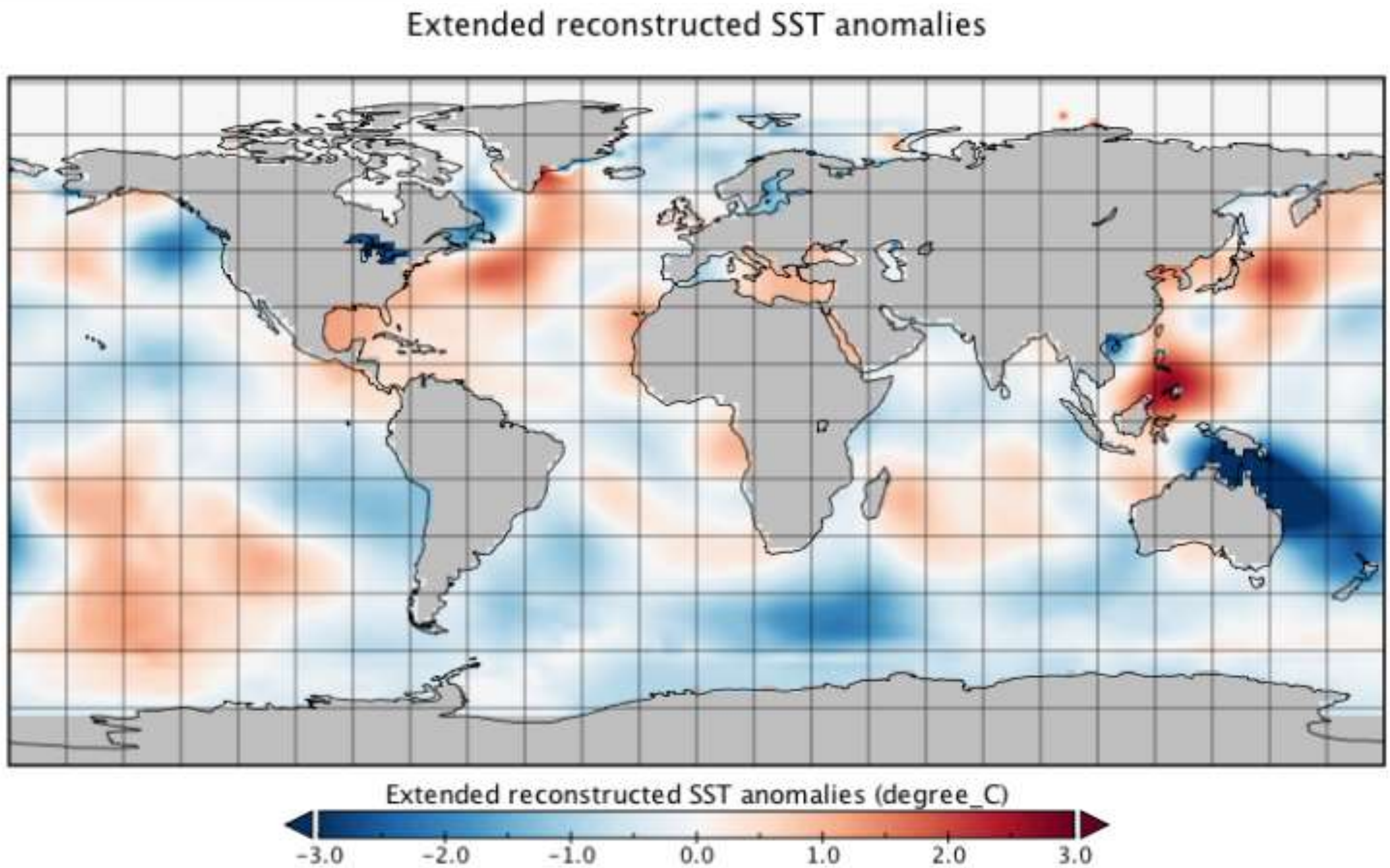
Step 10. Anomaly maps should always have a scale centered around zero so there is the same quantity both above and below zero. To change the scale, click on the **Scale** tab near the bottom of Panoply, as shown in the image below.

Then, change the **minimum** number in the **Scale Range to -3**, and the **maximum** number in **the Scale Range to 3**, as shown in the image below.

Next, change the **Divisions, Major to 6**, as shown in the image below.

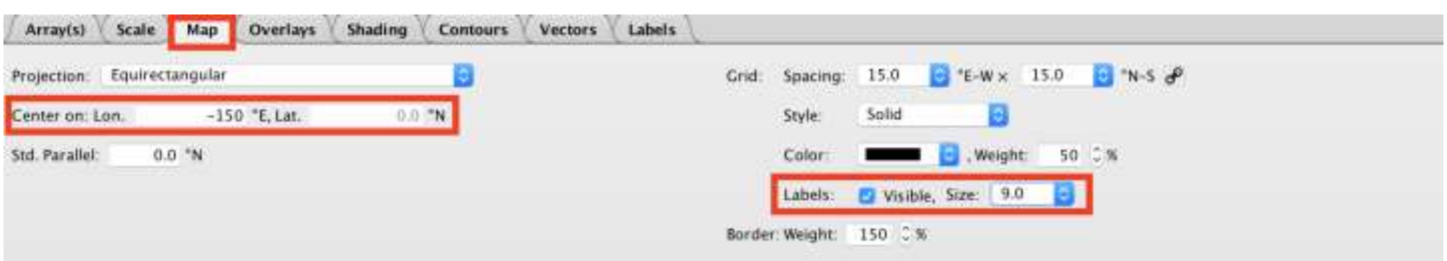
Step 11. Next, change the Color Table to **CB_RdBu.cpt** and then check the box for **Reverse colors**, as shown in the image below.

The map should now look like the map in the image below:

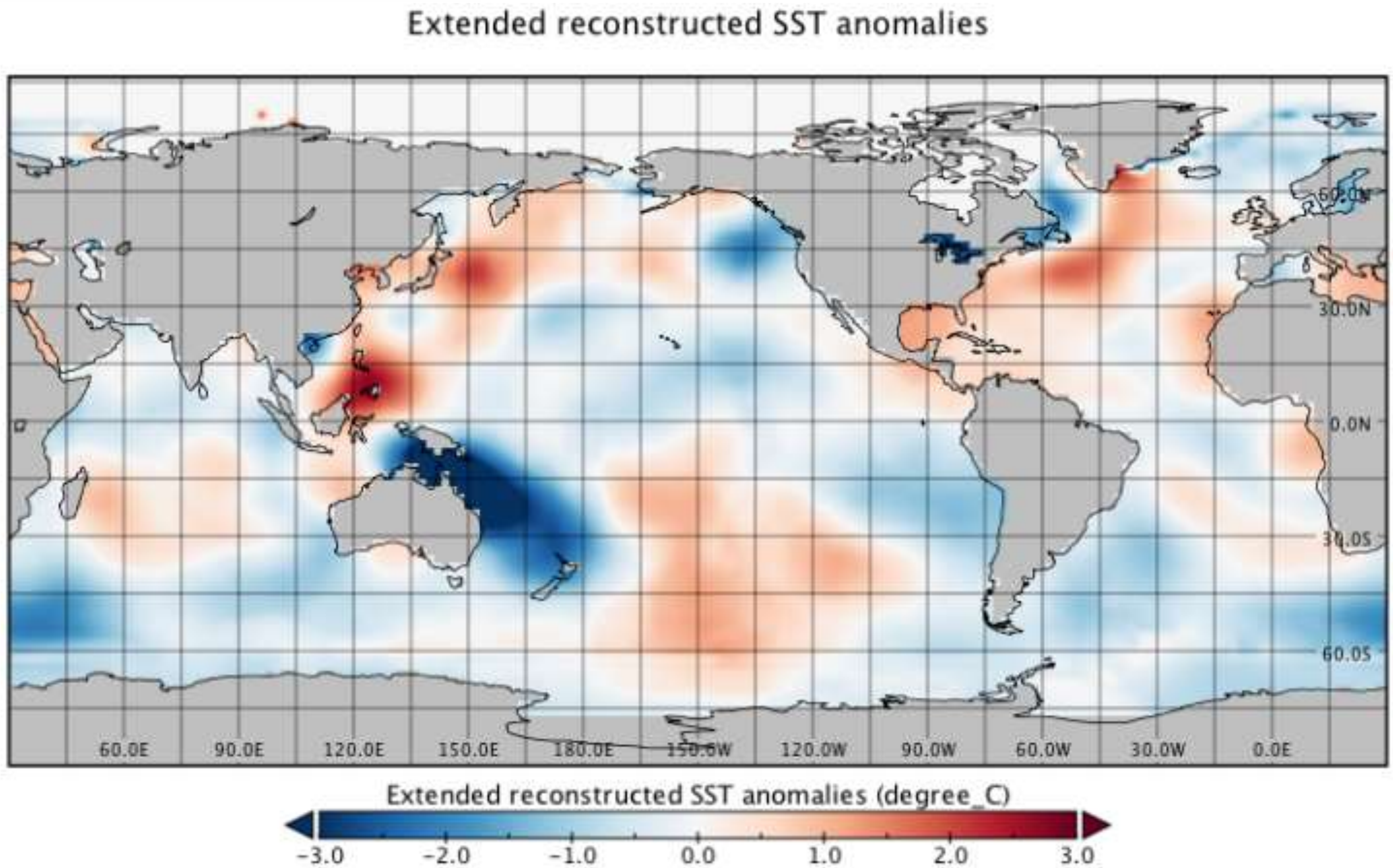


Step 12. The map is currently centered on 0˚ longitude. ENSO events take place in the equatorial Pacific Ocean, which should be the center of the map. To change the longitude the map is centered on, click on the **Map** tab near the bottom of Panoply, and then change the longitude to **-150 ˚E**, as shown in the image below.

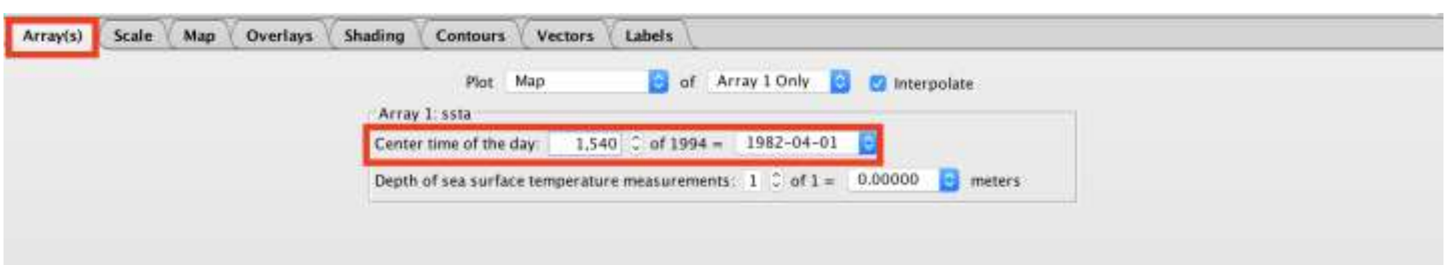
Also, check off the box for **Labels** and change the **Size** to **9.0** to display the latitude and longitude labels on the map, as shown in the image below.



This centers the map on 150˚W (-150˚E) longitude. Your map should now look like the map in the image below.



Step 13. Click on the Array(s) tab near the bottom of Panoply and change the **Center time of the day** to 1,540 to represent April 1982 (1982-04-01), as shown in the image below.



Step 14. Click on the up arrow to slowly change the **Center time of the day** from 1,540 (April 1982) to 1,554 (June 1983). Observe the sea surface temperature anomalies in the eastern equatorial Pacific Ocean.

Q3. Describe the type of sea surface temperature anomalies in the **eastern** equatorial Pacific Ocean between April 1982 and June 1983.

____

____

Q4. How did the sea surface temperature anomalies change in the **eastern** equatorial Pacific Ocean between April 1982 and June 1983?

____

____

Q5. The El Niño Southern Oscillation (ENSO) has three phases: El Niño, La Niña, and neutral. An El Niño event took place between 1982 and 1983. Based on your answers to Q1 – Q4 and your observations of the sea surface temperature anomalies in Panoply, define an El Niño event.

____

____

Step 15. Change the time slice to 1,634 to represent February 1990 and observe the sea surface temperatures in the equatorial Pacific Ocean.

Q6. How are the sea surface temperature anomalies in the equatorial Pacific Ocean in February 1990 different from the sea surface temperature anomalies from April 1982 to June 1983?

____

____

Q7. During February 1990, an El Niño event did not occur. Based on this information, change your definition of an El Niño event from Q5 and then explain your changes. If your answer does not change, explain why your answer remains the same based on the data.

Definition: ____

____

Explanation: ____

____

Step 16. Change the time slice to 1,743 to represent March 1999. Then, click on the up arrow to slowly change the time from 1,742 (March 1999) to 1,754 (February 2000). Observe the sea surface temperature anomalies in the eastern equatorial Pacific Ocean.

Q8. Describe the type of sea surface temperature anomalies in the **eastern** equatorial Pacific Ocean between March 1999 and February 2000.

____

____

Q9. How did the sea surface temperature anomalies change in the **eastern** equatorial Pacific Ocean between March 1999 and February 2000?

____

____

Q10. The El Niño Southern Oscillation (ENSO) has three phases: El Niño, La Niña, and neutral. A La Niña event took place between 1999 and 2000. Based on your answers to Q8 - Q11 and your observations of the sea surface temperature anomalies in Panoply, define a La Niña event.

____

____

Step 17. Change the time slice to 1777 to represent January 2002 and observe the sea surface temperatures in the equatorial Pacific Ocean.

Q11. How are the sea surface temperature anomalies in the equatorial Pacific Ocean in January 2002 different from the sea surface temperature anomalies from March 1999 to February 2000?

____

____

Q12. During January 2002, a La Niña event did not occur. Based on this information, change your definition of a La Niña event from Q12 and then explain your changes. If your answer does not change, explain why your answer remains the same based on the data.

Definition: ____

____

Explanation: ____

____

Q13. Change the time slice back to 1,634 to represent February 1990 and then change the time slice back to 1,777 to represent January 2002. Both of these months represent ENSO neutral events, which means neither an El Niño nor La Niña event was occurring.

Describe the evidence provided by the sea surface temperature anomalies in the equatorial Pacific Ocean that ENSO neutral events were occurring during these months.

____

____

____

Q14. Based on your findings from this activity, explain how climatologists use sea surface temperature anomalies in the equatorial Pacific Ocean to classify an El Niño event.

____

____

Q15. Based on your findings from this activity, explain how climatologists use sea surface temperature anomalies in the equatorial Pacific Ocean to classify a La Niña event.

____

____

EXPLORE – Part 2: Precipitation

Step 1. We will now explore the relationship between ENSO and precipitation. Go to this link to download precipitation data from Global Precipitation Climatology Project and look for the section titled **Download/Plot Data**. GPCP Precipitation data provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, from their Web site at https://psl.noaa.gov/

Step 2. Click on **precip.mon.mean.nc** as shown in the image below to download average monthly precipitation data. This dataset contains average monthly precipitation for every month from January 1979 to May 2020 for a total of 497 time slices, one for each month.

Note: The most recent time slice is May 2020 based on the time this activity was created. The dataset will contain more time slices as more time passes.

Download/Plot Data:

Variable	Statistic	Level	Download File	Create Plot/Subset
Precipitation	Monthly Mean		precip.mon.mean.nc	
Precipitation	Monthly Error Estimate		precip.mon.mean.error.nc	
Precipitation	Monthly LTM (1981-2010)		precip.mon.ltm.nc	

Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **precip.mon.mean.nc.** For simplicity, change the name of the file to **precip.nc** by right-clicking on the dataset and selecting “rename”.

Step 3. Next, click on **precip.mon.ltm.nc** as shown in the image below to download the long-term monthly average precipitation. This dataset contains the average precipitation between 1981 and 2010 for the month of January, February, March, etc. This means this dataset contains only 12 time slices, one for each month.

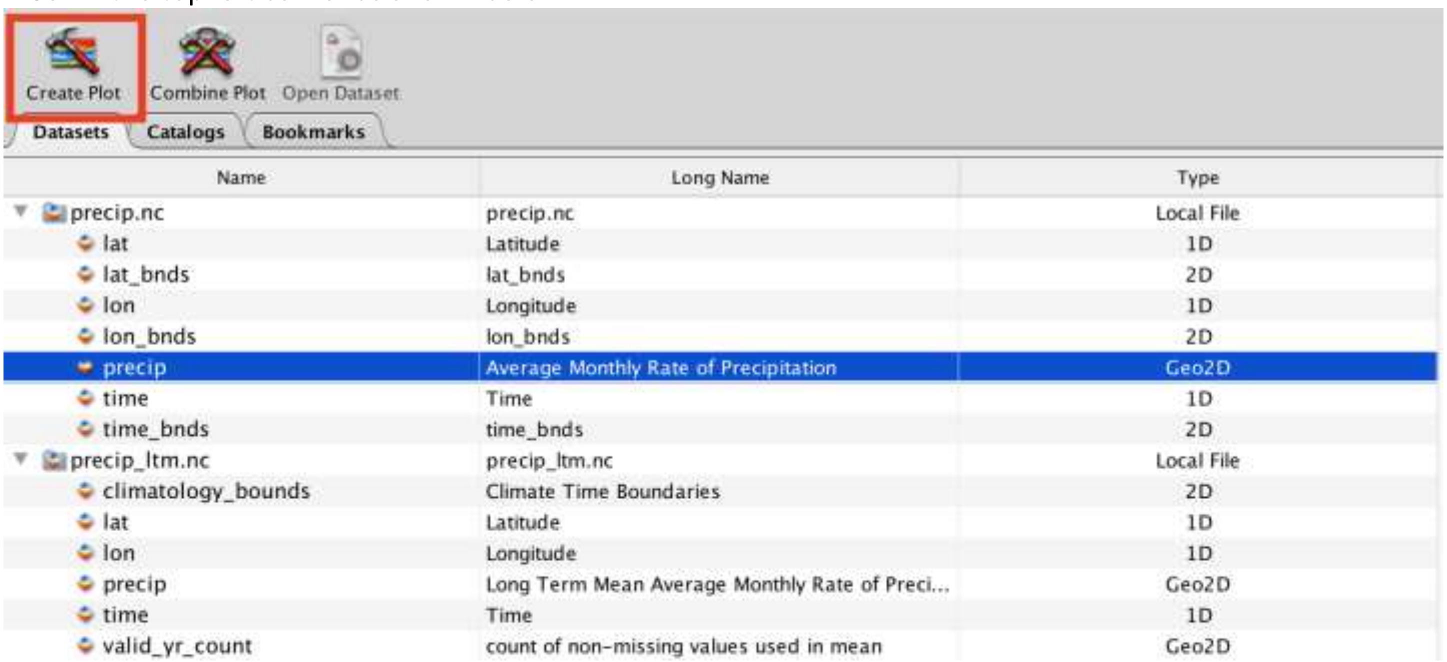
Download/Plot Data:

Variable	Statistic	Level	Download File	Create Plot/Subset
Precipitation	Monthly Mean		precip.mon.mean.nc	
Precipitation	Monthly Error Estimate		precip.mon.mean.error.nc	
Precipitation	Monthly LTM (1981-2010)		precip.mon.ltm.nc	

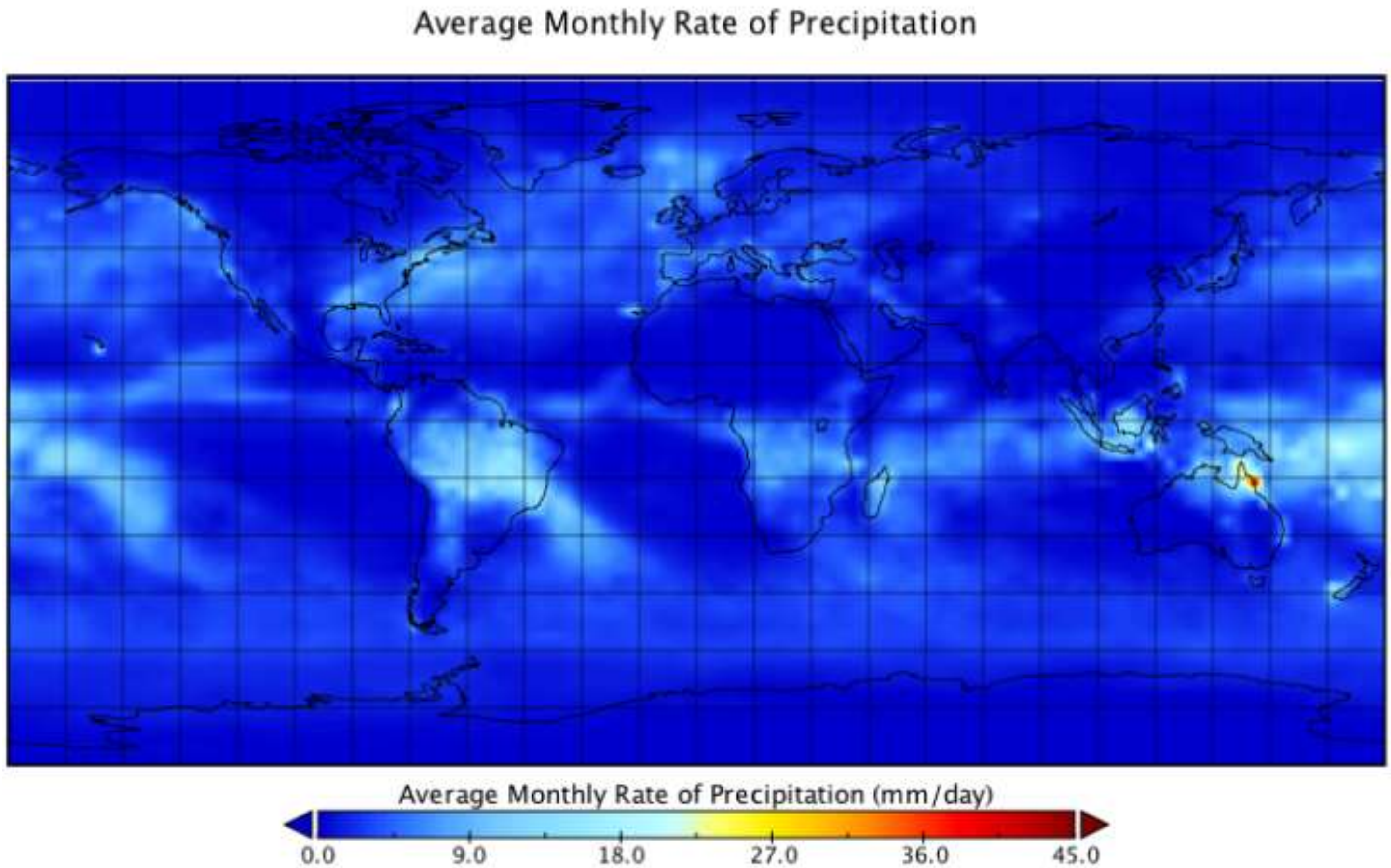
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **precip.mon.ltm.nc.** For simplicity, change the name of the file to **precip_ltm.nc** by right-clicking on the dataset and selecting "rename".

Step 4. Open the **precip.nc** and **precip_ltm.nc** datasets in Panoply.

Step 5. In Panoply, go to the **precip.nc** dataset and click on the variable titled **"precip"** and then click **"Create Plot"** in the top left corner as shown below:

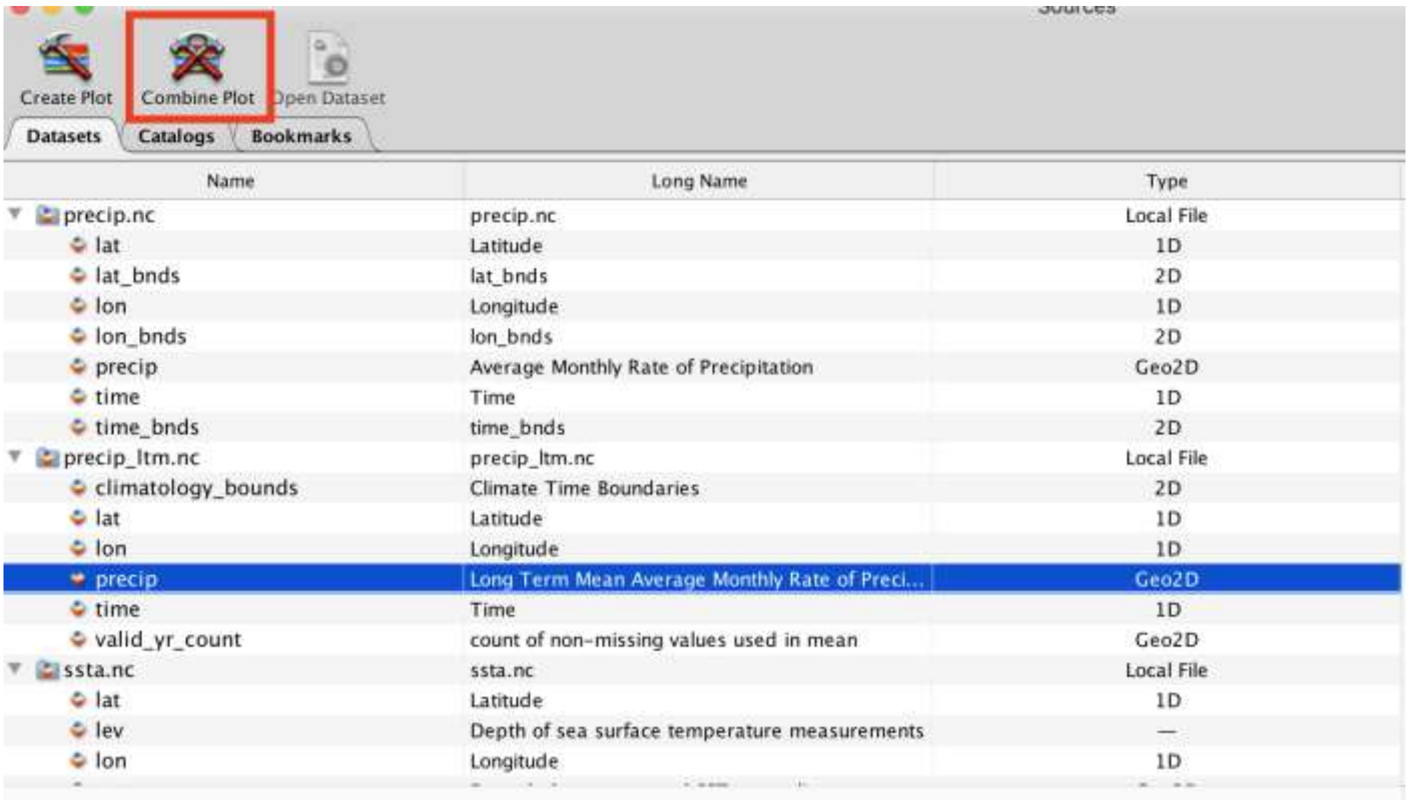


When prompted, click **Create** again and you should see a map that looks like the following:

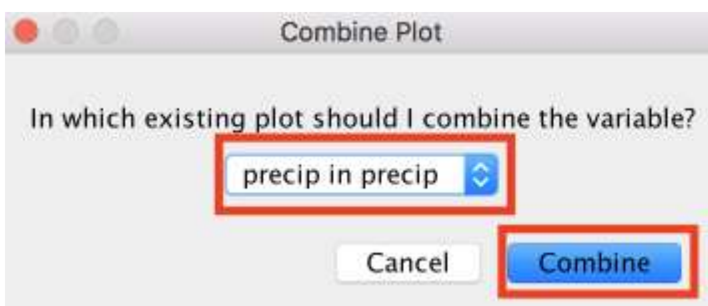


Step 6. Go back to the main window of Panoply and under the **precip_ltm.nc** dataset, click on the **precip** variable as shown in the image below.

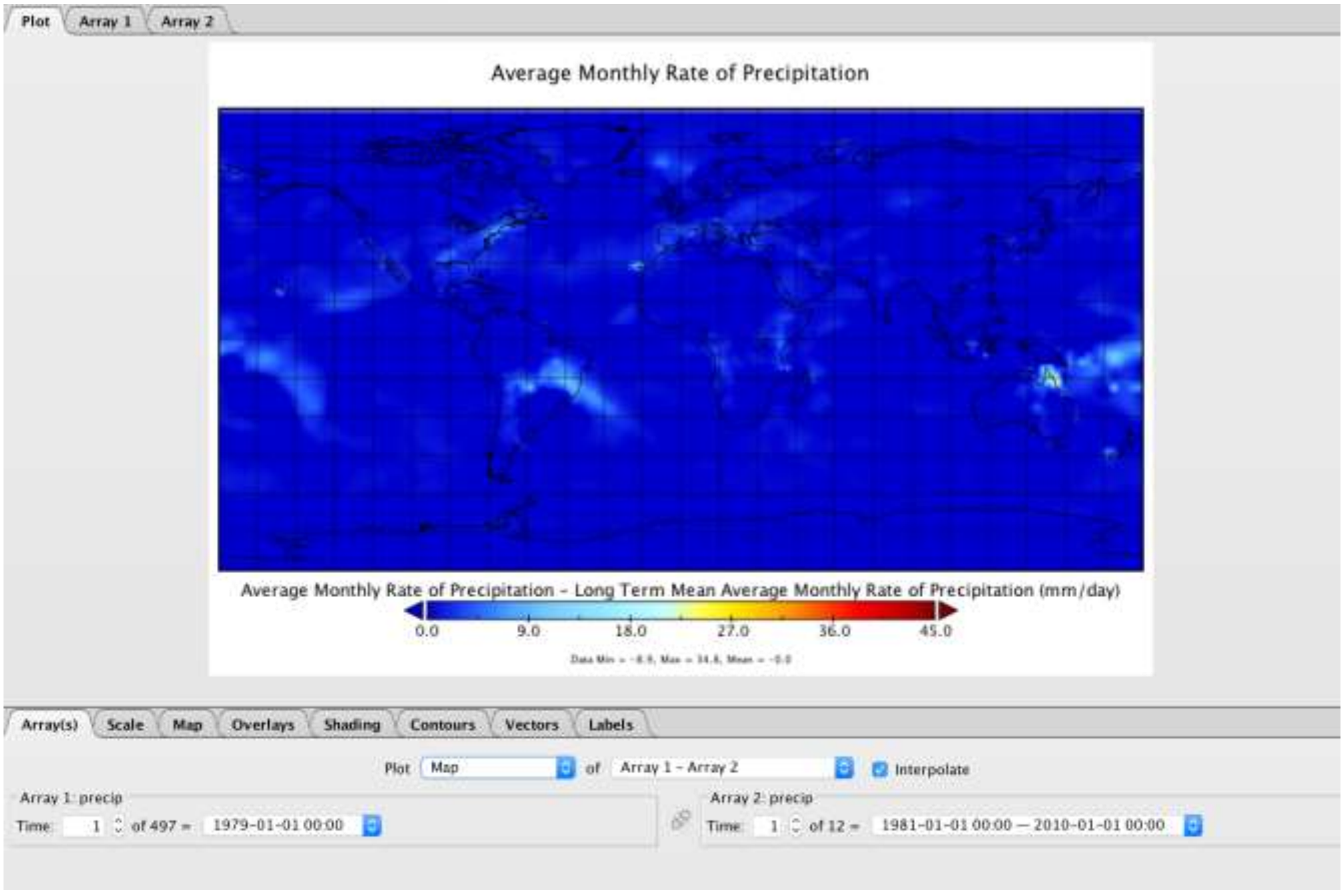
Then, click on **Combine Plot** as shown in the image below.



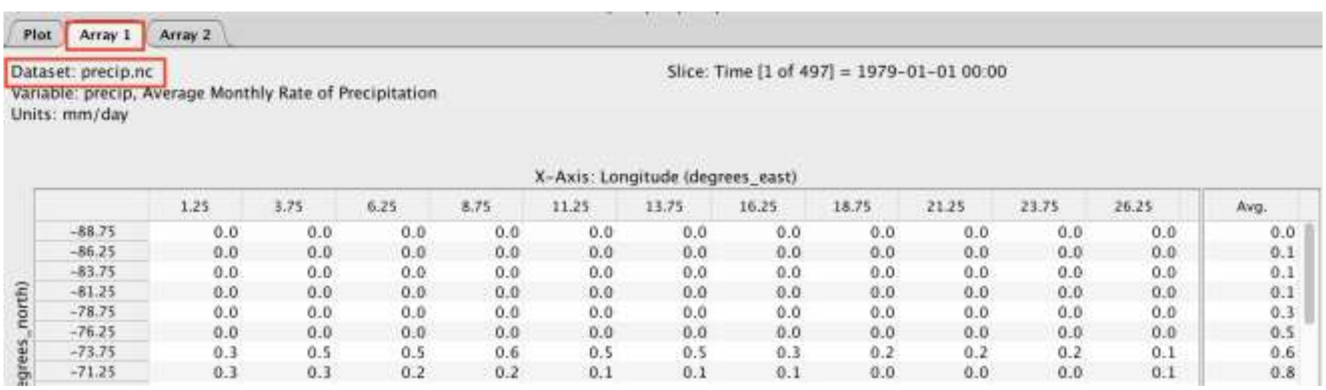
Step 7. Make sure you have **precip in precip** selected, and then click **Combine**, as shown in the image below.



These actions allow for both the **precip.nc** and **precip_ltm.nc** data to both be viewable in the plot window of Panoply. You should now see a map that looks like the following:

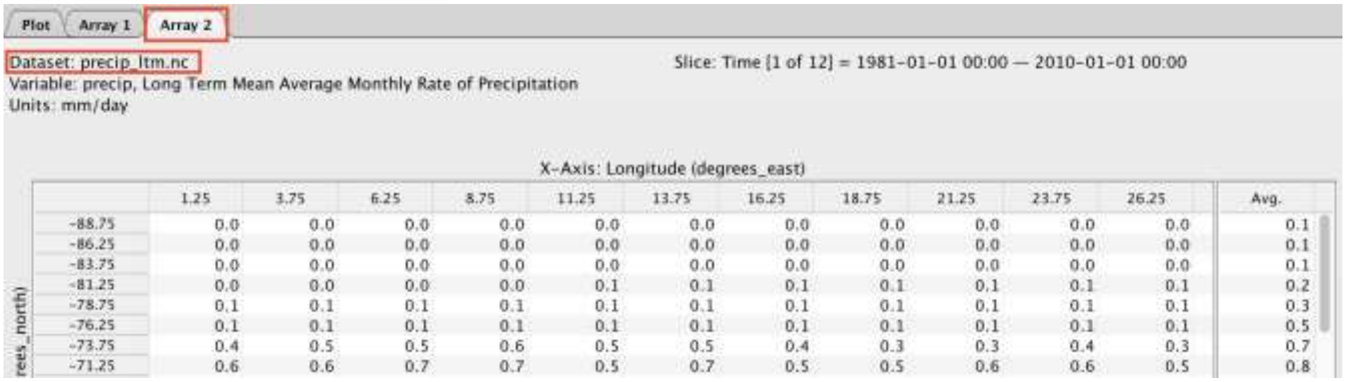


Step 8. Near the top of Panoply, click on the **Array 1** tab and you should see that the dataset in Array 1 is **precip.nc**. This is shown in the image below.



	1.25	3.75	6.25	8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	Avg.
-88.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-86.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-83.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-81.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-78.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
-76.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
-73.75	0.3	0.5	0.5	0.6	0.5	0.5	0.3	0.2	0.2	0.2	0.1	0.6
-71.25	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.8

Step 9. Next, click on **Array 2** to ensure that the dataset in this array **is precip_ltm.nc**, as shown below.



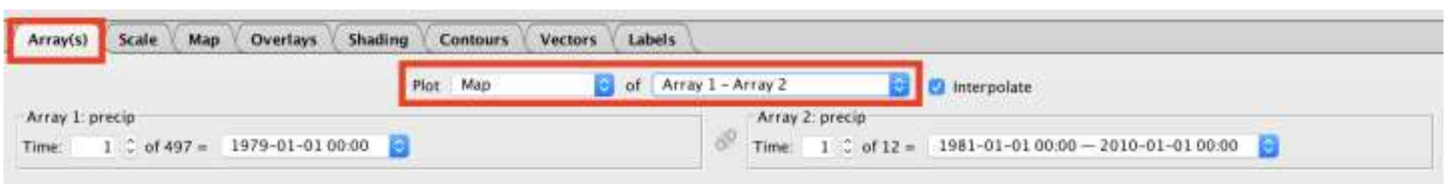
	1.25	3.75	6.25	8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	Avg.
-88.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-86.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-83.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-81.25	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
-78.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
-76.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5
-73.75	0.4	0.5	0.5	0.6	0.5	0.5	0.4	0.3	0.3	0.4	0.3	0.7
-71.25	0.6	0.6	0.7	0.7	0.5	0.7	0.5	0.5	0.6	0.6	0.5	0.8

Step 10. Our purpose of combining the **precip.nc** and **precip_ltm.nc** data is to create a dataset that represents the precipitation anomaly. To calculate an anomaly, the long-term average (**precip.ltm.nc**) needs to be subtracted from the monthly data (**precip.nc**). This calculation is shown below:

Precipitation Anomaly = precip.nc – precip_ltm.nc

Now that the data is combined, this calculation can be done directly in Panoply.

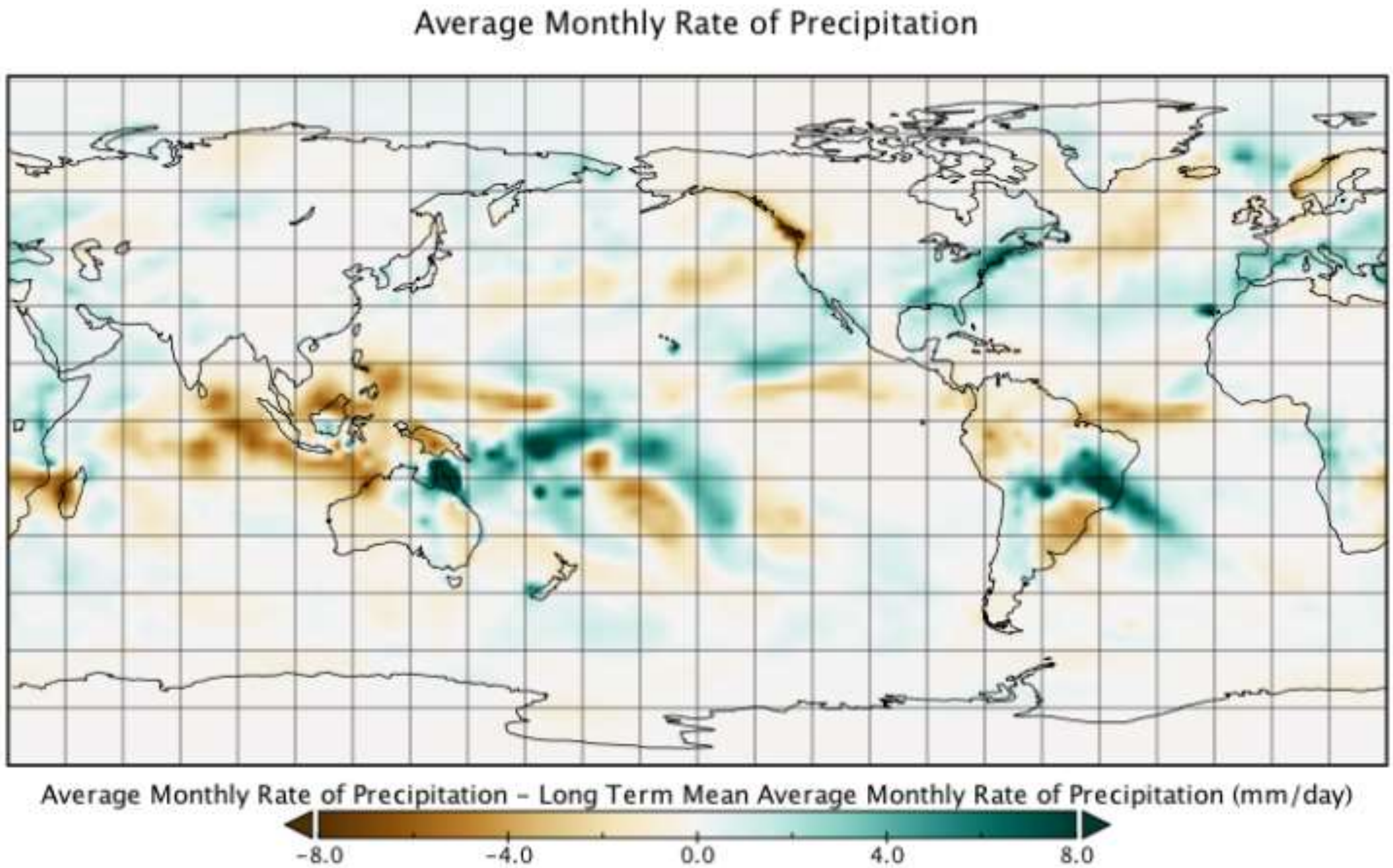
Step 11. Click on the **Plot** tab near the top left of Panoply. Then, click on the **Array(s)** tab near the bottom of Panoply. Make sure that Array 1 – Array 2 is selected, as shown in the image below. This setting means Panoply is creating a map based on the subtraction of Array 1 – Array 2, which is **precip.nc** – **precip_ltm.nc**.



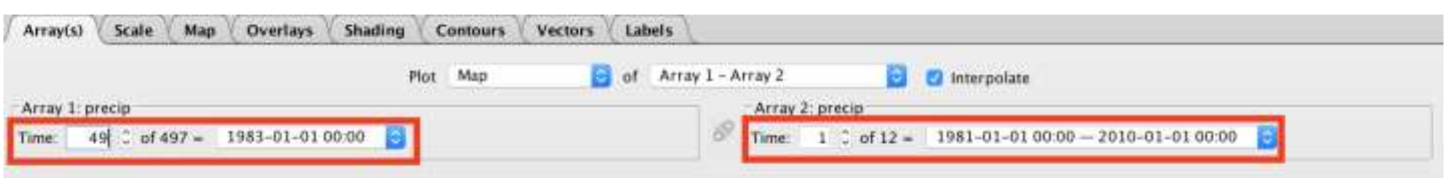
Step 12. Go to the **Map** tab near the bottom of Panoply and change the settings to center the map on 150˚W longitude by typing in **-150˚E**.

Next, go to the **Scale** tab and change the scale range so the **Min** is **-8** and the **Max** is **8**. Change the **Divisions, Major** to **4** and then change the **Color Table** to **CB_BrBG.cpt.** This is all displayed in the image below.

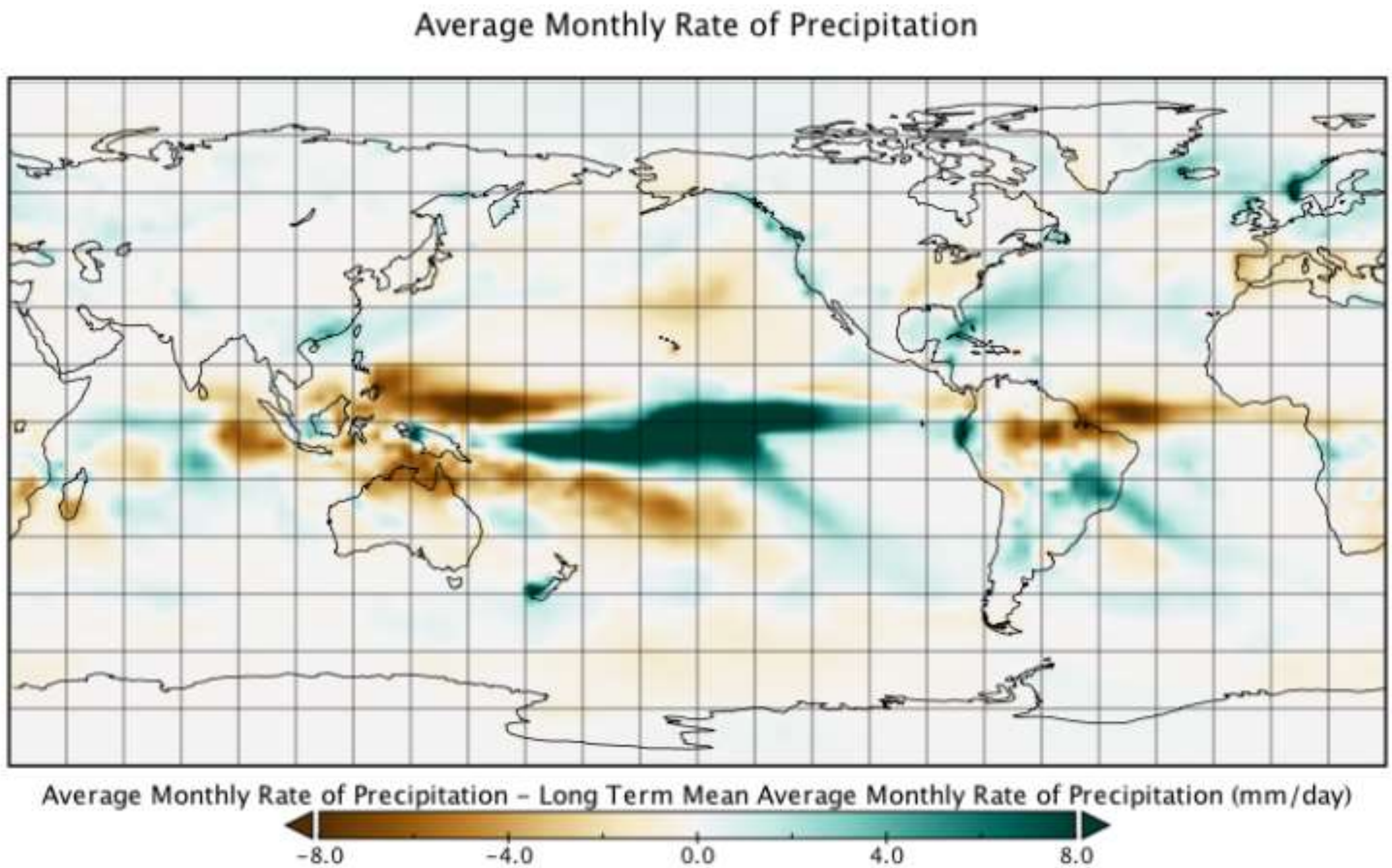
Step 13. Your map should now look like the map below:



Step 14. Go to the **Array(s)** tab near the bottom of Panoply and change the time slice for Array 1 to **49** to represent the average precipitation during January 1983 (1983-01-01 00:00), a time during an El Niño event. Then, change the time slice for Array 2 to **1**, to represent the long-term monthly average for the month of January. These settings result in Panoply calculating the precipitation anomaly for the month of January 1983. The image below shows these settings.



Step 15. Your map should now look like the map below:



Q1. What does a positive precipitation anomaly mean?

____

____

Q2. Describe the general location on the map where there are the greatest positive precipitation anomalies.

____

____

Q3. What does a negative precipitation anomaly mean?

____

____

Q4. Describe the general location on the map where there are the greatest negative precipitation anomalies.

____

____

Step 16. Change the time for Array 1 to **230** and the time for Array 2 to **2** to represent precipitation anomalies during February 1998, a time during another El Niño event.

Q5. ***Circle one option below.*** In general, is the location with the greatest **<u>positive</u>** precipitation anomalies for the El Niño event in February 1998 similar to or different from the location for the El Niño event in December 1982?

Similar ***Different***

Q6. ***Circle one option below.*** In general, is the location with the greatest **<u>negative</u>** precipitation anomalies for the El Niño event in February 1998 similar to or different from the location for the El Niño event in December 1982?

Similar ***Different***

Step 17. Change the time for Array 1 to **444** and the time for Array 2 to **12** to represent precipitation anomalies during December 2015, a time during another El Niño event.

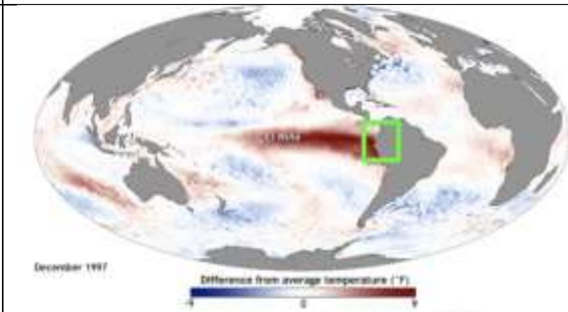
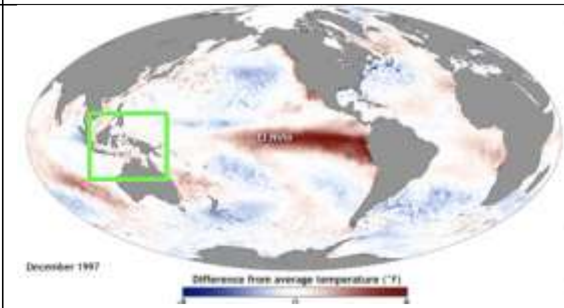
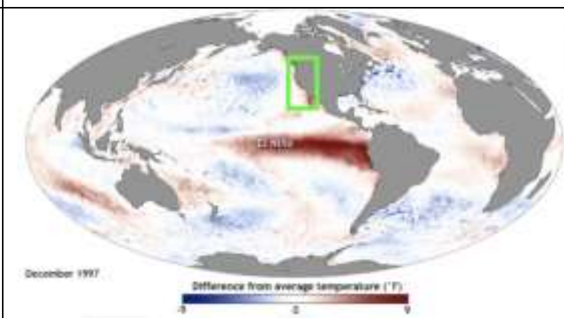
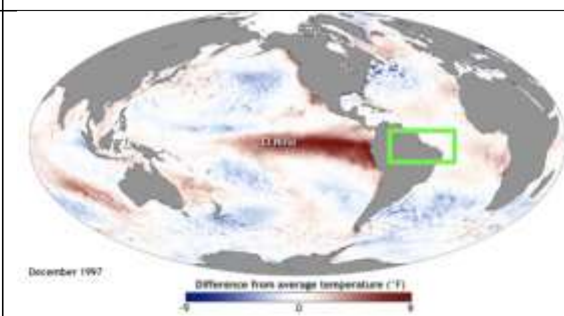
Q7. ***Circle one option below.*** In general, is the location with the greatest **<u>positive</u>** precipitation anomalies for the El Niño event in December 2015 similar to or different from the location for the El Niño event in December 1982 and February 1998?

Similar ***Different***

Q8. ***Circle one option below.*** In general, is the location with the greatest **<u>negative</u>** precipitation anomalies for the El Niño event in December 2015 similar to or different from the location for the El Niño event in December 1982 and February 1998?

Similar ***Different***

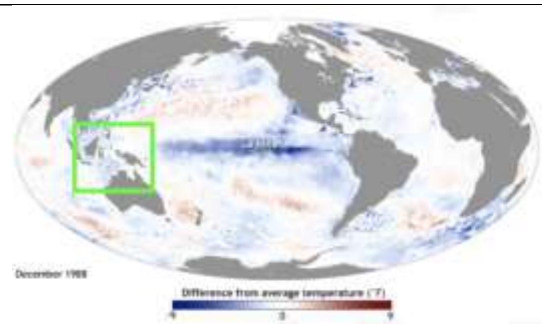
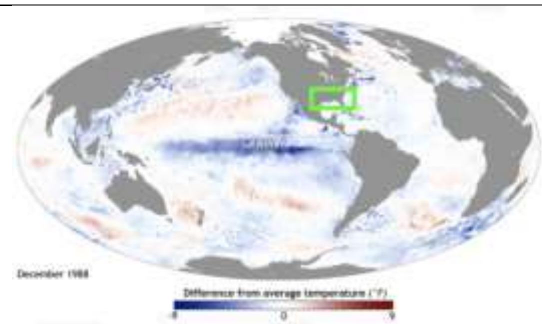
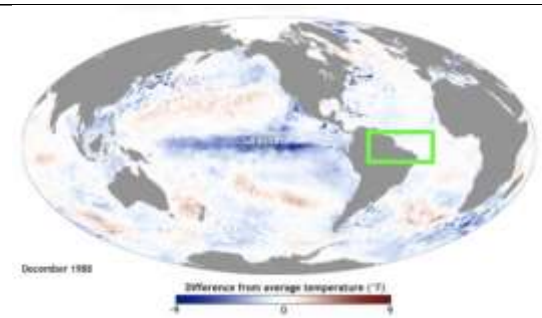
Q9. The data table below is similar to the one in the previous ENGAGE activity. After reviewing the precipitation anomalies for the winter months during three different El Niño events, describe whether each location experiences more or less precipitation than normal in the winter during El Niño events.

Location	Map	El Niño Impact on Winter Precipitation
West coast of South America		
Southeast Asia and Australia		
West Coast of North America		
East Coast of South America		

Step 18. We will now explore precipitation anomalies in winter months during La Niña events, which is referred to as the cold phase of ENSO. Using Panoply, analyze the precipitation anomalies for the following three La Niña events:

- **December 1988** (Change Array 1 to **120** and Array 2 to **12**)
- **December 1999** (Change Array 1 to **252** and Array 2 to **12**)
- **December 2010** (Change Array 1 to **384** and Array 2 to **12**)

Q10. After reviewing the precipitation anomalies for the winter months during three different La Niña events, describe whether each location experiences more or less precipitation than normal in the winter during La Niña events.

Location	Map	La Niña Impact on Winter Precipitation
Southeast Asia and Australia		
Southeast Coast of North America		
Northeast Coast of South America		

EXPLAIN

Step 1. The goal of our EXPLAIN activity is to be able to uncover why El Niño and La Niña events occur and lead to the temperature and precipitation anomalies observed.

El Niño events are classified when the sea surface temperature anomalies in the eastern equatorial Pacific Ocean are 0.5˚C or greater for three consecutive months, while La Niña events are classified when the anomalies are -0.5˚C or less for three consecutive months.

Q1. What are the criteria for classifying an El Niño and La Niña event?

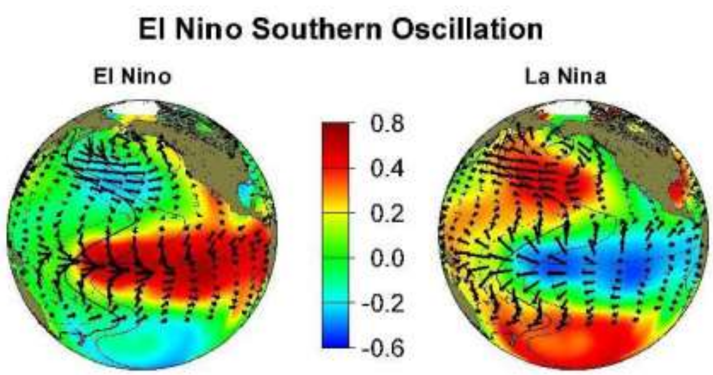
El Niño: ____

____

La Niña: ____

____

One of the driving factors influencing ENSO events is the direction of the wind that results from the changing pressure in the eastern and western equatorial Pacific Ocean. The diagram below from NOAA, [which can be accessed at this GLOBE resource,] shows the varying wind speeds and directions associated with El Niño and La Niña events. The direction of the arrows correspond to the wind direction and the length of the arrow corresponds to the speed of the wind; the longer the arrow, the greater the windspeed. The maps are both centered on the equatorial Pacific Ocean.



Q2. Based on the diagram above, compare the general windspeed and direction in the eastern equatorial Pacific Ocean during El Niño and La Niña events.

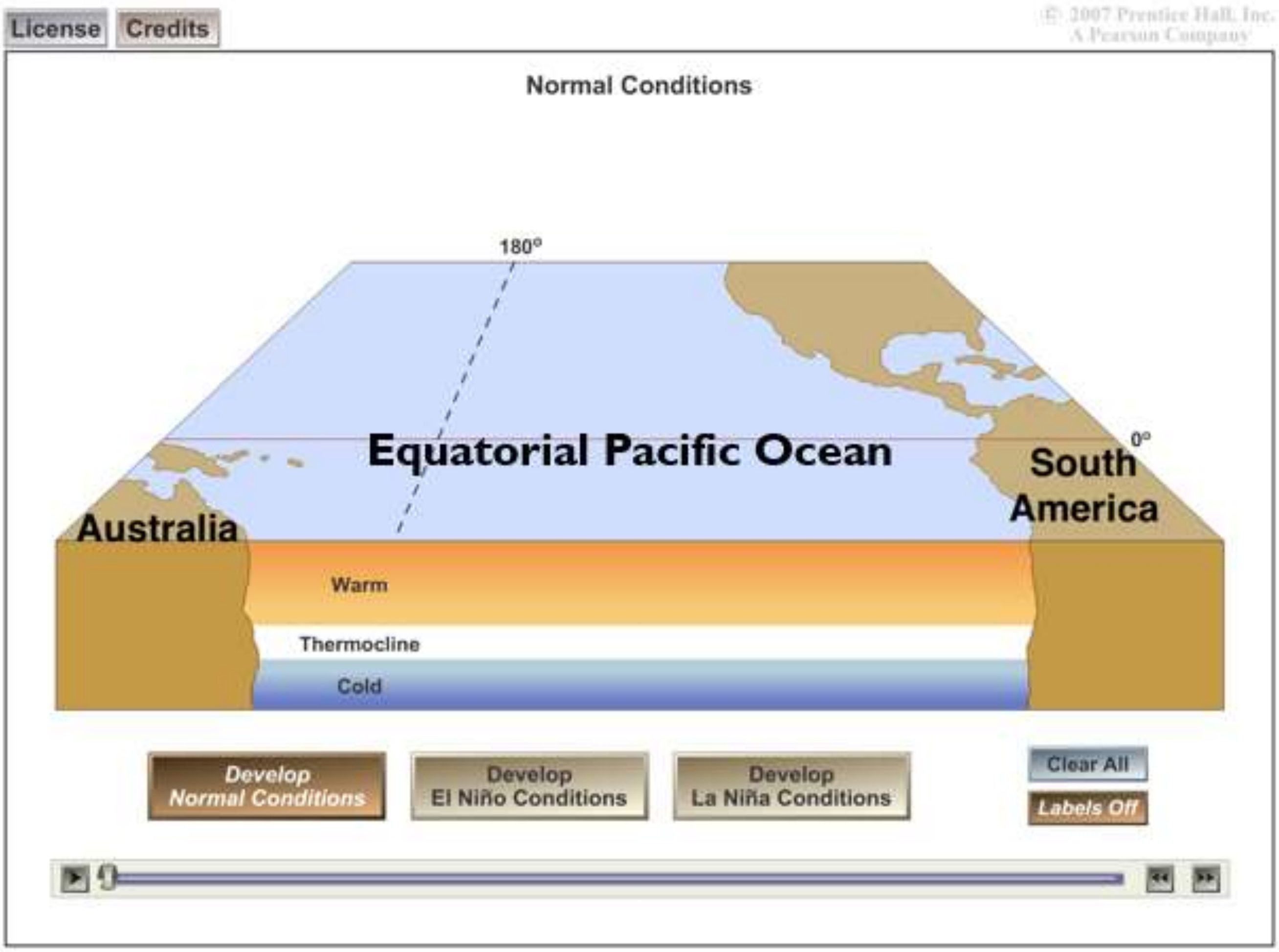
____

____

Step 2. [Go to this link to view an ENSO simulation.] You will be brought to a page with three different animations: one for Normal Conditions, one for El Niño Conditions, and another for La Niña Conditions. The El Niño Southern Oscillation (ENSO) has three phases; a normal phase, a warm phase (El Niño), and a cold phase (La Niña).

Through the simulation, you will first investigate the changes in sea surface temperature, precipitation, and air pressure. Then, you will be able to explain why those changes occur based on the changing wind patterns.

Step 3. Make sure your animation is set to Normal Conditions, as shown in the screenshot below.



***Note the addition of labels for South America and Australia in the screenshot above to help identify the landmasses on either side of the equatorial Pacific Ocean. Additionally, the thermocline is defined as the boundary between warmer water near the surface and colder water below.**

Step 4. Click the play button (triangle) in the bottom left corner of the animation to view atmospheric conditions during the Normal state of ENSO. Make sure the animation plays the entire way through.

Q3. After viewing the Normal Conditions animation, describe in general where the colder surface water is located.

____

____

Q4. After viewing the Normal Conditions animation, describe where the high-pressure system is generally located.

____

____

Q5. How is this high pressure impacting the amount of precipitation of the region that it is in?

____

____

Q6. After viewing the Normal Conditions animation, describe where the warmer surface water is generally located.

____

____

Q7. After viewing the Normal Conditions animation, describe where the low-pressure system is generally located.

____

____

Q8. How is this low pressure impacting the amount of precipitation of the region that it is in?

____

____

Step 5. Near the bottom of the animation, click on **Develop El Niño Conditions** and then press play to see how the ocean and atmosphere change due to El Niño conditions. Be sure to play this animation all the way to the end to see the entire development of El Niño conditions.

Q9. After viewing the El Niño Conditions animation, describe how the sea surface temperature changed in the eastern equatorial Pacific Ocean (near South America).

SST in eastern equatorial Pacific Ocean (near South America): ____

____

____

Q10. After viewing the El Niño Conditions animation, describe how the pressure changed over the eastern equatorial Pacific Ocean (near South America) and the western equatorial Pacific Ocean (near Australia).

Pressure in eastern equatorial Pacific Ocean (near South America): ____________________________________

____

Pressure in western equatorial Pacific Ocean (near Australia): ____

____

Q11. After viewing the El Niño Conditions animation, describe how the amount of precipitation changed over the eastern equatorial Pacific Ocean (near South America) and the western equatorial Pacific Ocean (near Australia).

Precipitation in eastern equatorial Pacific Ocean (near South America): _________________________________

____

Precipitation in western equatorial Pacific Ocean (near Australia): _____________________________________

____

Step 6. Refresh the animation and click **Develop Normal Conditions** and watch the entire animation. Then, click **Develop El Niño Conditions** and watch the entire animation. This time when you play the animations, pay attention to the changes in wind patterns and surface ocean currents as conditions transition from Normal to El Niño conditions.

Note: The solid black arrows represent the movement of surface ocean currents.

Note: The red arrows show the direction of surface winds.

Q12. As El Niño conditions develop, describe how the movement of the surface ocean currents changed in the equatorial Pacific Ocean.

____

____

Q13. As El Niño conditions develop, describe how the direction of the surface winds changed in the equatorial Pacific Ocean.

____

____

Q14. As El Niño conditions develop, what happens to the temperature of the surface ocean water along the northwest coast of South America (eastern equatorial Pacific Ocean)?

____

____

Why does the temperature change water in this region?

____

____

Q15. As El Niño conditions develop, what type of pressure develops in the eastern Pacific Ocean (near the northwest coast of South America). Then, explain why there was a change in pressure.

Pressure in eastern equatorial Pacific Ocean (near South America): ____________________________

Explanation: ____

____

Q16. As El Niño conditions develop, describe what happens to the amount of precipitation in the eastern Pacific Ocean (near the northwest coast of South America) and the western equatorial Pacific Ocean (near Australia). For each region, also explain why there was a change in the amount of precipitation.

Precipitation in eastern equatorial Pacific Ocean (near South America): _________________________

Explanation: ____

____

Precipitation in western equatorial Pacific Ocean (near Australia): ____________________________

Explanation: ____

____

Q17. Write a brief summary to explain why there is more precipitation in the eastern equatorial Pacific Ocean and less precipitation in the western equatorial Pacific Ocean during El Niño events. Your answer should include information about the surface ocean currents, surface winds, air pressure, and sea surface temperature.

____

____

____

Step 7. Near the bottom of the animation, click on **Develop La Niña Conditions** and then press play to see how the ocean and atmosphere change due to La Niña conditions. Be sure to play this animation all the way to the end to see the entire development of La Niña conditions.

Q18. Write a brief summary to explain why there is less precipitation in the eastern equatorial Pacific Ocean and more precipitation in the western equatorial Pacific Ocean during La Niña events. Your answer should include information about the surface ocean currents, surface winds, air pressure, and sea surface temperature.

____

____

____

____

ELABORATE

While many locations in the middle and high latitudes experience seasons influenced mostly by temperature, many tropical locations around the world experience a wet and a dry season. The Amazon located in the northern region of South America experiences a wet and a dry season. Although it can vary from location to location, the dry season in the Amazon corresponds with the Southern Hemisphere winter, which takes place from about June to November. On the other hand, the wet season corresponds with the Northern Hemisphere winter, which takes place from about December to April.

Wildfires in the Amazon usually increase during the dry season months. However, the number of wildfires during the 2016 dry season were higher than the amount from previous years. It is believed that there was an increase due to a lower amount of rainfall in the preceding wet season from December 2015 to April 2016.

Your task is to determine if there is a relationship between ENSO and the increase in wildfires in the Amazon in 2016. Complete the tasks below and then answer the summary question.

- Go to this link to access the Mapping the Amazon resource from the NASA Earth Observatory to view a map that shows the location of the Amazon and its extent within South America.
- Analyze the sea surface temperature anomaly data in Panoply to determine the ENSO phase during the months preceding the 2016 Amazon dry season. Use the instructions from EXPLORE #1 as a guide.
- Analyze the precipitation anomaly data in Panoply to determine how precipitation in the Amazon region was impacted during the months preceding the 2016 Amazon dry season. Use the instructions from EXPLORE #2 as a guide.

Question: Based on your knowledge of ENSO and the sea surface temperature and precipitation anomaly data, identify whether an El Niño, La Niña, or ENSO neutral (normal phase) event took place and then explain how this ENSO phase resulted in the large-scale wildfire outbreak in the Amazon in 2016.

____

____

____

____

____

____

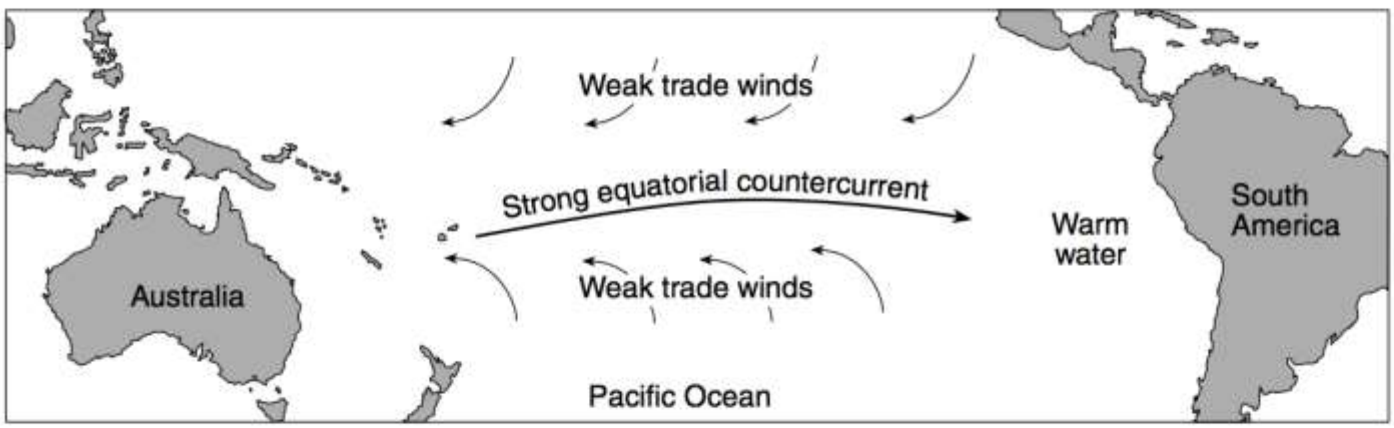
EVALUATE – Questions used and adapted from the New York State Earth Science Regents.

Q1. What is the name of the climate event that occurs when surface water in the eastern equatorial area of the Pacific Ocean becomes warmer than normal and may cause a change in global precipitation patterns?

____

Q2. The map below shows the weak trade winds and strong equatorial countercurrent in the Pacific Ocean during El Niño conditions. This causes warm surface ocean water to migrate eastward, lowering the atmospheric pressure above this warm water. The diagram and question are from the New York State Earth Science Regents.

El Niño Conditions



What are the most likely changes to atmospheric temperature and precipitation along the west coast of South America during El Niño conditions?

(1) lower temperatures and lower amounts of precipitation
(2) lower temperatures and higher amounts of precipitation
(3) higher temperatures and lower amounts of precipitation
(4) higher temperatures and higher amounts of precipitation

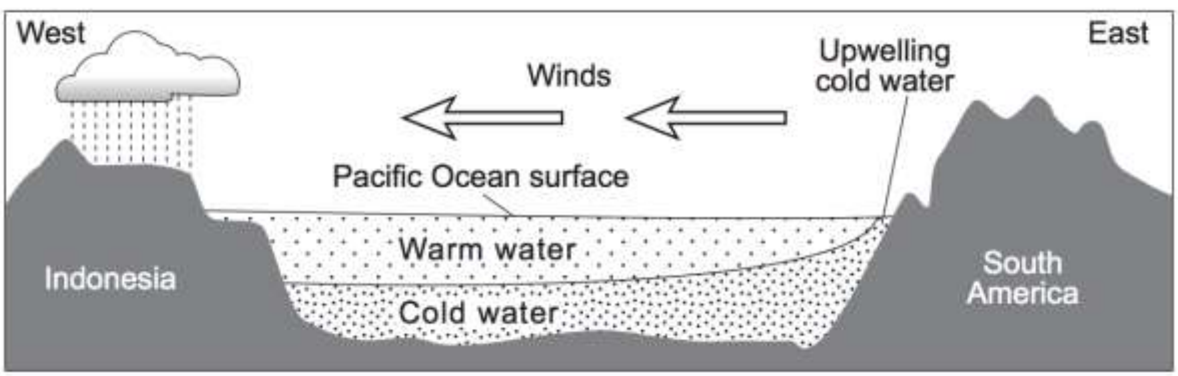
Base your answers to questions 3 through 5 on the passage and cross section below and on your knowledge of Earth science. The cross section represents a generalized region of the Pacific Ocean along the equator during normal (non-El Niño) conditions. The relative temperatures of the ocean water and the prevailing wind direction are indicated. The passage, diagram, and questions are from the New York State Earth Science Regents.

El Niño

Under normal Pacific Ocean conditions, strong winds blow from east to west along the equator. Surface ocean water piles up on the western part of the Pacific due to these winds. This allows deeper, colder ocean water on the eastern rim of the Pacific to be pulled up (upwelling) to replace the warmer surface water that was pushed westward.

During an El Niño event, these westward-blowing winds get weaker. As a result, warmer water does not get pushed westward as much, and colder water in the east is not pulled toward the surface. This creates warmer surface ocean water temperatures in the east, allowing the thunderstorms that normally occur at the equator in the western Pacific to move eastward. A strong El Niño is often associated with wet winters along the northwestern coast of South America and in the southeastern United States, and drier weather patterns in Southeast Asia (Indonesia) and Australia. The northeastern United States usually has warmer and drier winters in an El Niño year.

Normal Pacific Ocean Conditions (non-El Niño years)



(Not drawn to scale)

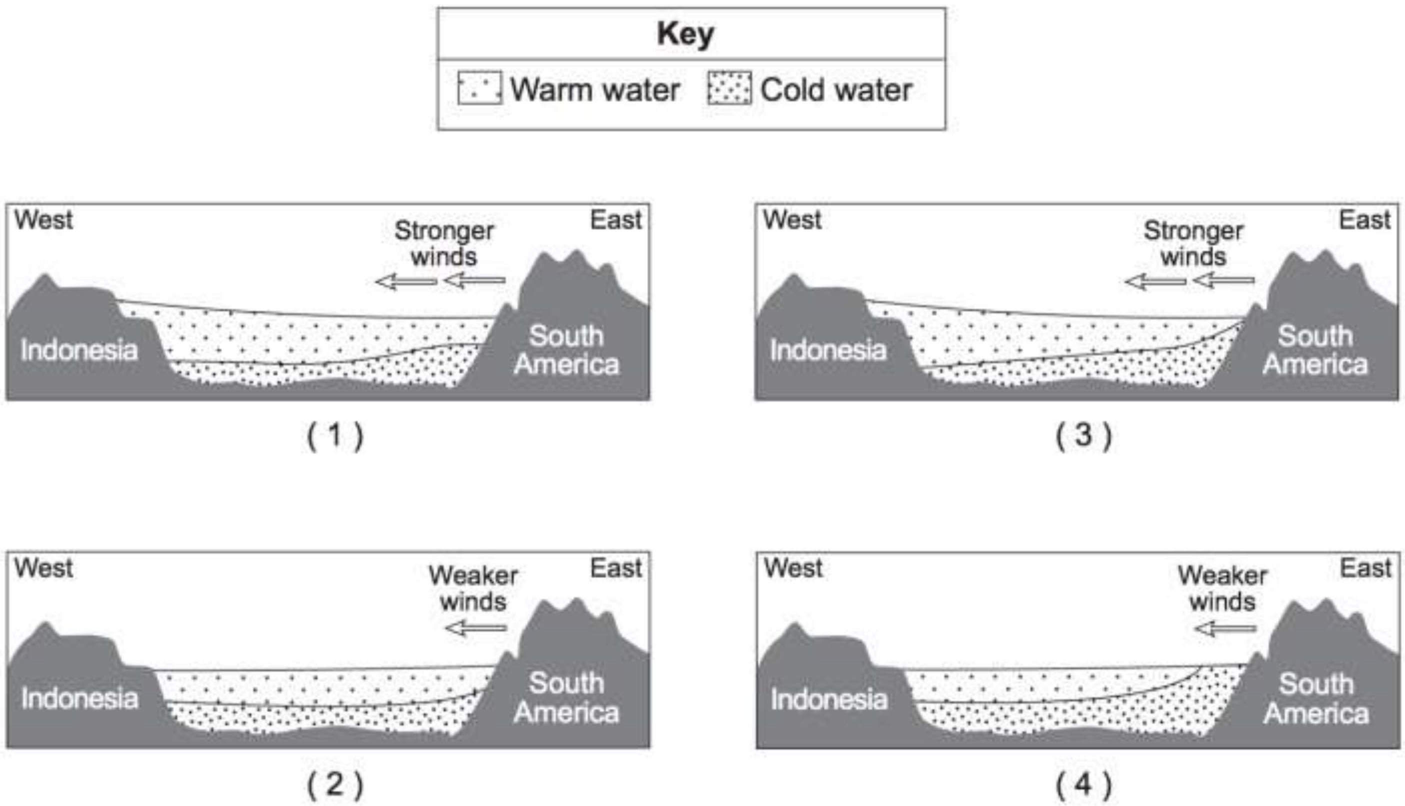
Q3. Compared to non-El Niño years, which climatic conditions exist near the equator on the western and eastern sides of the Pacific Ocean during an El Niño event?

(1) The western Pacific is drier and the eastern Pacific is wetter.
(2) The western Pacific is wetter and the eastern Pacific is drier.
(3) The western and the eastern Pacific are both wetter.
(4) The western and the eastern Pacific are both drier.

Q4. During an El Niño year, winter climatic conditions in New York State will most likely be

(1) colder and wetter (2) warmer and wetter (3) colder and drier (4) warmer and drier

Q5. Which cross section best represents the changed wind conditions and Pacific Ocean temperatures during an El Niño event? [Diagrams are not drawn to scale.]



National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Answers - ENSO & Wildfires Activity

Investigative Phenomenon – The El Niño Southern Oscillation (ENSO) can influence global climate patterns.

ENGAGE

Step 1. This is the link to a video about the development of the 2015 El Niño event. Click the link to view the simulation. After viewing the simulation, individually generate three questions you have about the development of the 2015 El Niño event in the space below.

Questions:

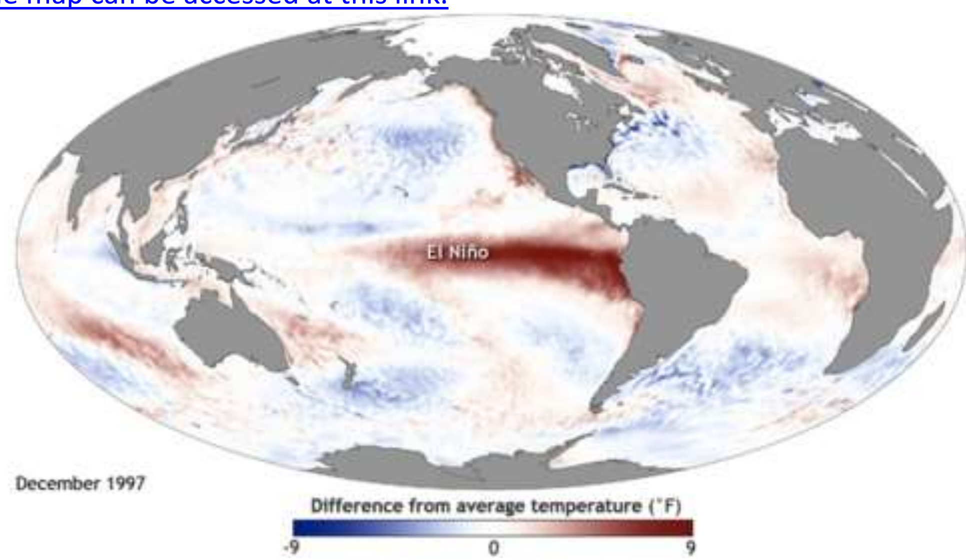
A. Student generated questions will vary

B. Student generated questions will vary

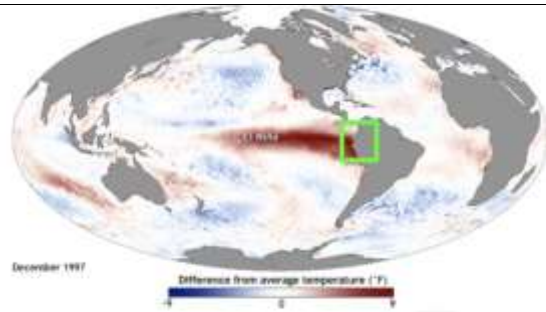
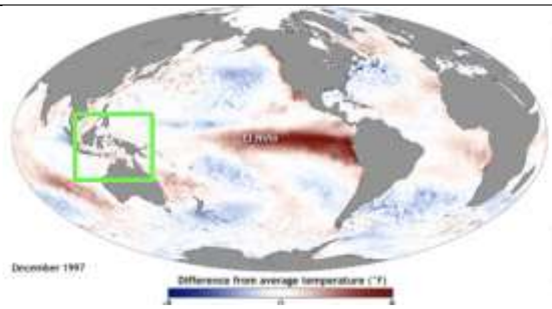
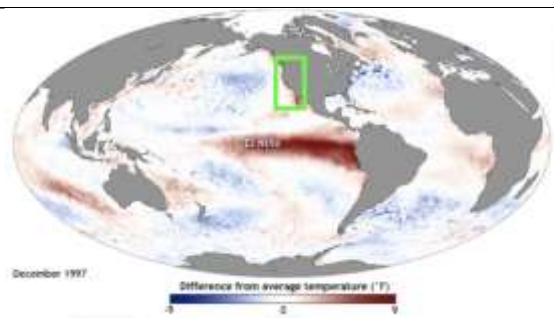
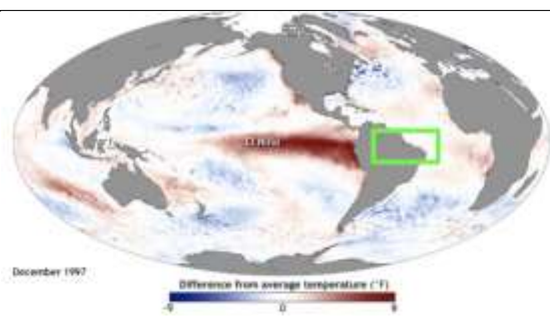
C. Student generated questions will vary

Step 2. With your group, set a timer for 5 minutes. Then, each group member will share the three questions generated. After all group members share, put a star next to any question that was repeated more than once, as well as any question that sparked an interest within the group. Use the remaining time to answer any starred questions based on your prior knowledge and experiences. Use the Turn & Discuss Quality Criteria to guide your discussion.

Step 3. The image below shows sea surface temperatures during an El Niño event. The red colors represent sea surface temperature values that are warmer than normal, which is the meaning of an El Niño event. The greatest above normal temperatures are in the eastern equatorial Pacific Ocean, off of the northwest coast of South America. The map can be accessed at this link.



Q1. El Niño events and the warming of water occur in the eastern equatorial Pacific Ocean but can impact the precipitation patterns of locations around the world. For each general location in the data table below, identify how you think the amount of precipitation will be impacted. Then, explain your thinking.

Location	Map	Impact on Precipitation (Increase or Decrease)
West coast of South America		**Impact**: Increase **Explanation**: **Answers will vary. It is more important that students explain their thinking based on previously learned concepts rather than responding correctly.**
Southeast Asia and Australia		**Impact**: Decrease **Explanation**: **Answers will vary. It is more important that students explain their thinking based on previously learned concepts rather than responding correctly.**
West Coast of North America		**Impact**: Increase **Explanation**: **Answers will vary. It is more important that students explain their thinking based on previously learned concepts rather than responding correctly.**
East Coast of South America		**Impact**: Decrease **Explanation**: **Answers will vary. It is more important that students explain their thinking based on previously learned concepts rather than responding correctly.**

EXPLORE – Part 1: Sea Surface Temperature Anomaly

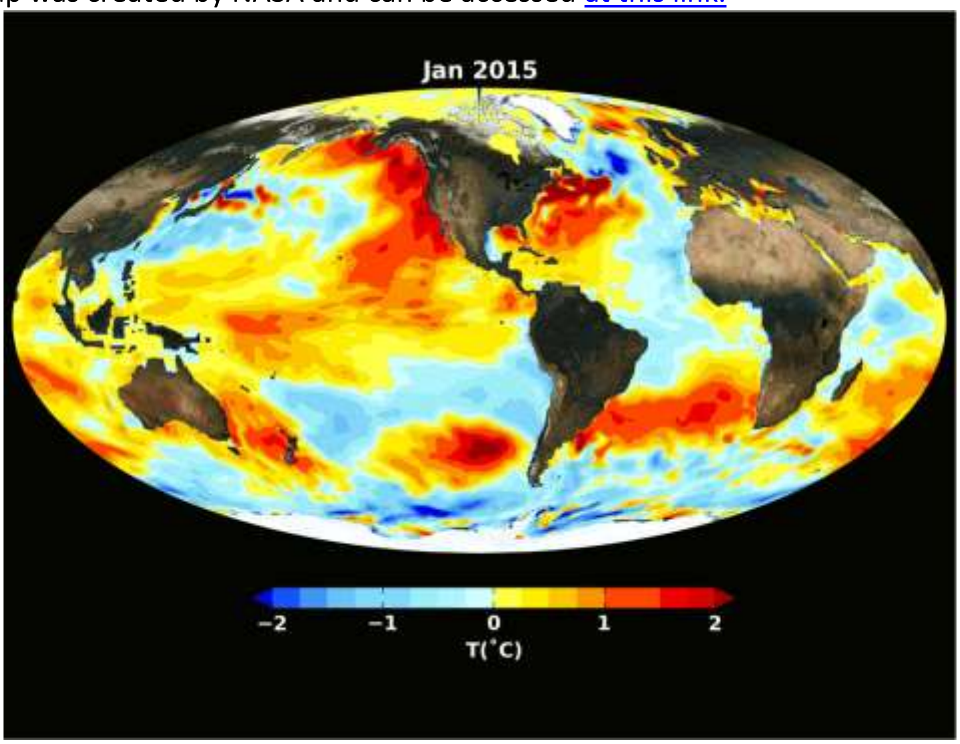
Step 1. To explore different El Niño events and other phases of ENSO, we will investigate sea surface temperature anomaly data. An anomaly describes how far above or below a value is from the average. For example, a sea surface temperature anomaly describes how far above or below a value is from the average sea surface temperature.

Q2. If the sea surface temperature anomaly for a location in the Atlantic was -4˚C, it does not mean the sea surface temperature was -4˚C. A temperature anomaly of -4˚C means the sea surface temperature that day was 4 degrees below (cooler than) the average temperature.

Based on this information, what would a sea surface temperature anomaly of 1˚C mean for a location in the Atlantic Ocean?

A sea surface temperature anomaly of 1˚C means that the sea surface temperature in the Atlantic Ocean is 1˚C above the average temperature. In short, the water temperature is 1˚C warmer than normal.

Step 2. Negative anomalies indicate values that are below average, while positive anomalies indicate values that are above average. The map below shows global sea surface temperature anomalies from January 2005. The blue colors represent negative anomalies, while the yellow, orange, and red colors represent positive anomalies. The map was created by NASA and can be accessed at this link.



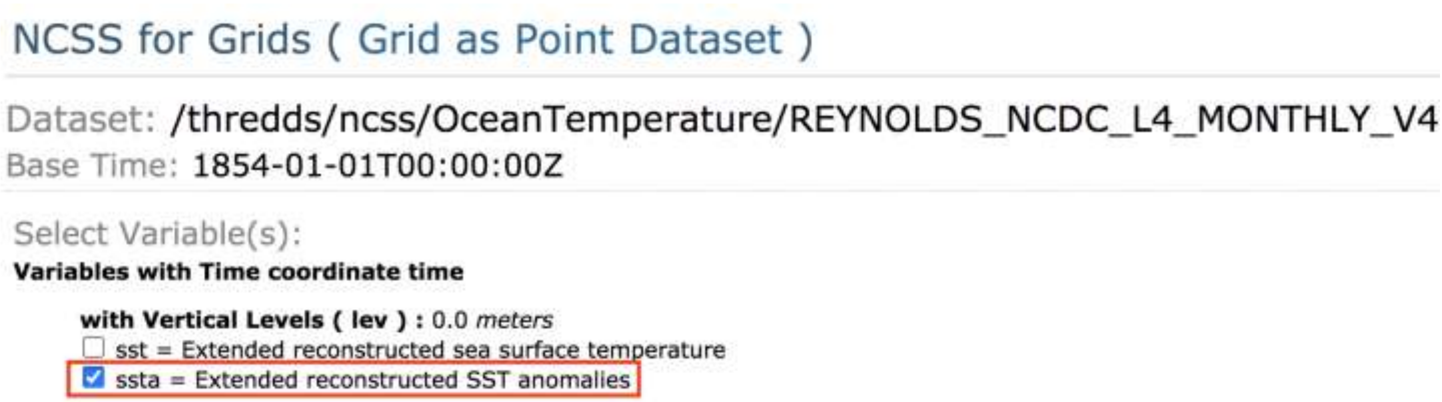
Q3. Identify whether the west coast of North America experienced a positive or negative sea surface temperature anomaly in January 2005. Then, explain what the anomaly means for sea surface temperature in that region.

Anomaly: **Positive sea surface temperature anomaly**

Explanation: **A positive sea surface temperature anomaly means that the ocean water temperature is warmer than average (normal).**

Step 3. Go to this link to access global monthly sea surface temperature anomaly data.

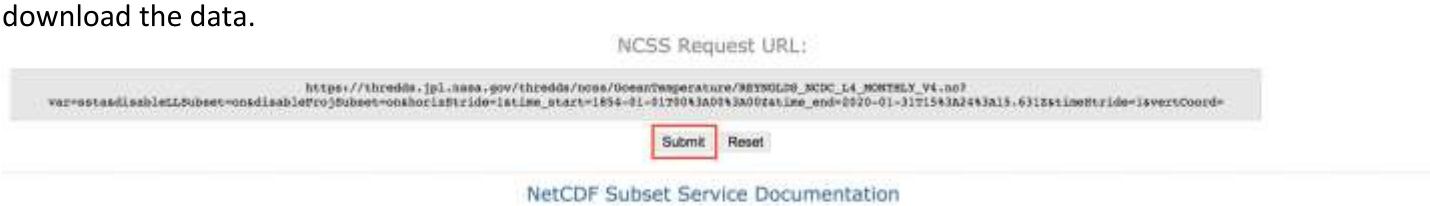
Step 4. Near the top left side of the page, locate "Select Variable(s)". Then, check the box for **ssta**, as shown in the image below.



Step 5. The right side of the page contains settings to change the location area of the data and the time range of the data. **Do not change any of the settings!**

- Since we want global sea surface temperature anomaly data, we want to download data for all latitude and longitude coordinates.
- We also want to download all monthly data from January 1854 to the most up to date month and year. At the time this activity was created, the most up to date month and year was January 2020, but this will change over time.

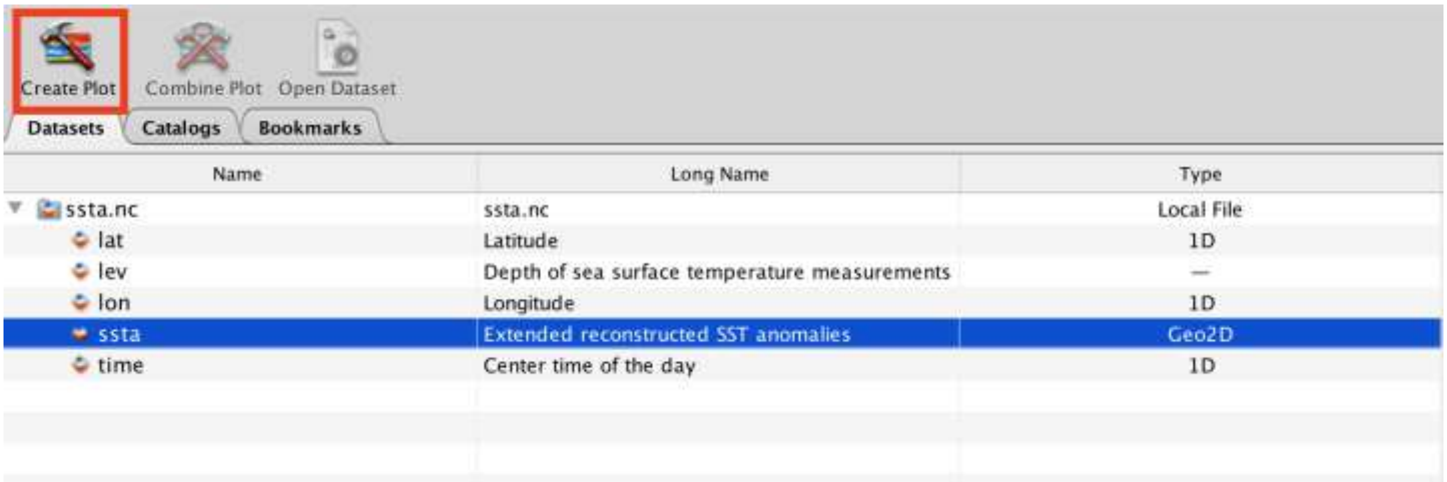
Step 6. Scroll down to the bottom of the page and click **Submit**, as shown in the image below. This will download the data.



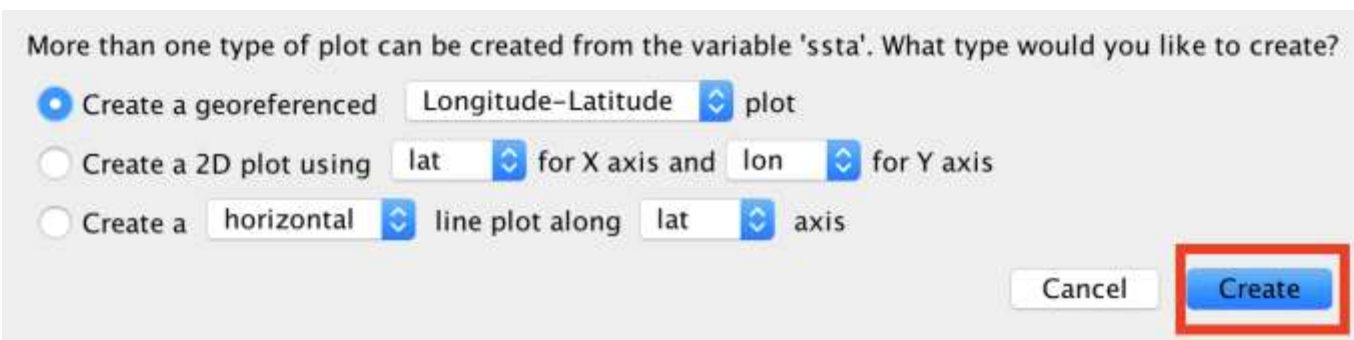
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **REYNOLDS_NCDC_L4_MONTHLY_V4.nc.** For simplicity, change the name of the file to **ssta.nc** by right-clicking on the dataset and selecting "rename".

Step 7. Open the Panoply program. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the **ssta.nc** file you saved in your downloads earlier and open it in Panoply. This dataset provides average monthly sea surface temperature anomalies for the entire Earth.

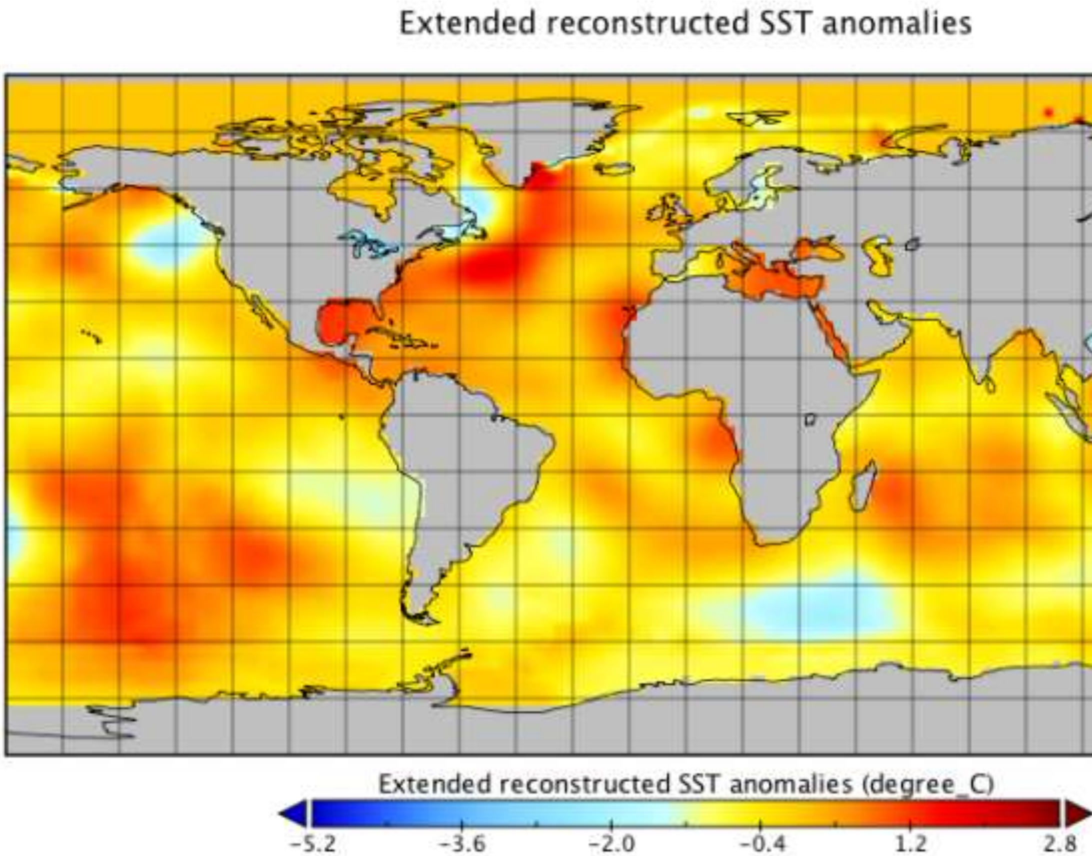
Step 8. Click on the variable titled **"ssta"** and then click **"Create Plot"** in the top left corner as shown below:



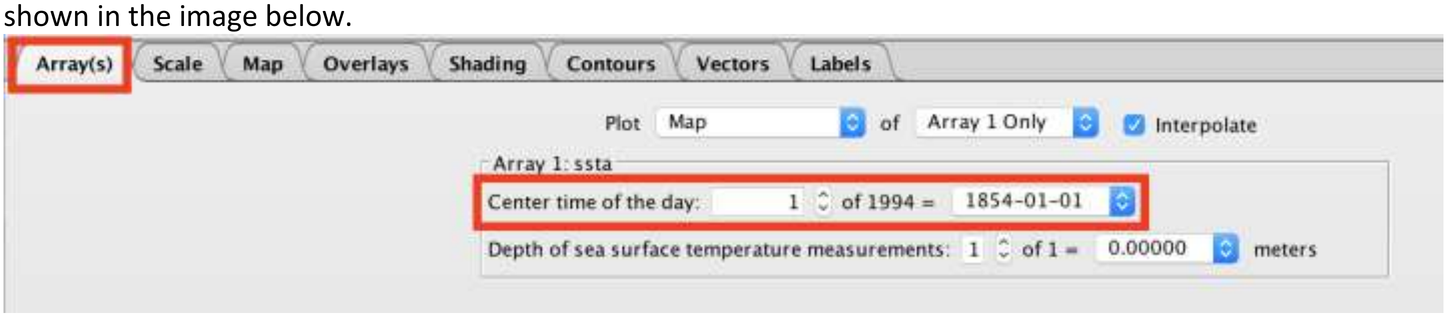
The following window will appear. Do not change any of the settings and click **"Create"** as shown below.



You should now see a map that looks like this:



Step 9. The map currently displayed is the average sea surface temperature anomaly during the month of January 1854 (1854-01-01). This can be verified by clicking on the **Array(s)** tab near the bottom of Panoply, as shown in the image below.



At the time this activity was created, the downloaded sea surface temperature anomaly data (**ssta**) contained 1,994 time slices. This means there are 1,994 months' worth of data between January 1854 and January 2020. January 1854 corresponds with time slice 1 of 1,994.

***Note:** The number of time slices could be higher if the data is downloaded after January 2020. As more monthly data is added to **ssta.nc**, the number of time slices will increase.

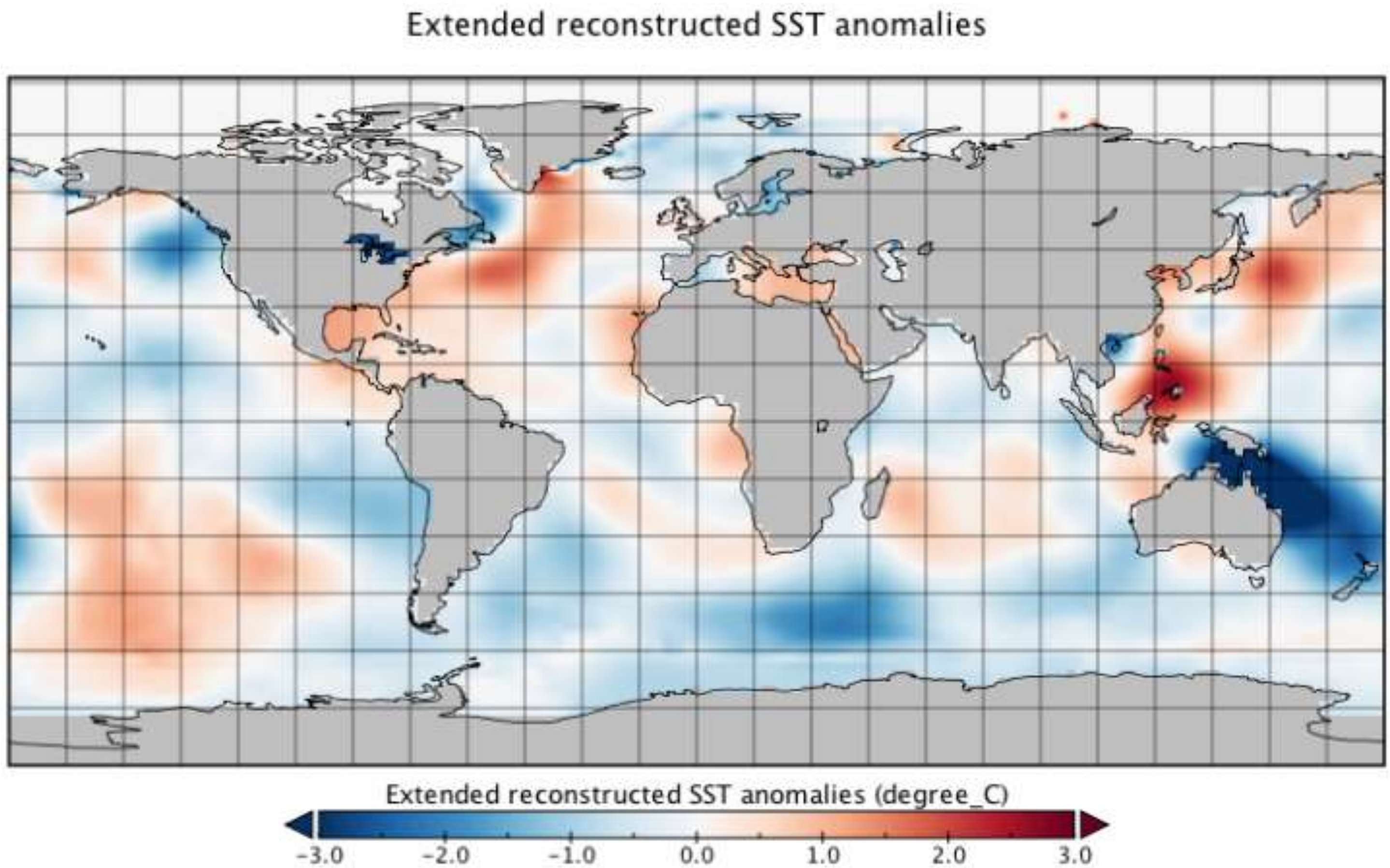
Step 10. Anomaly maps should always have a scale centered around zero so there is the same quantity both above and below zero. To change the scale, click on the **Scale** tab near the bottom of Panoply, as shown in the image below.

Then, change the **minimum** number in the **Scale Range to -3**, and the **maximum** number in **the Scale Range to 3**, as shown in the image below.

Next, change the **Divisions, Major to 6**, as shown in the image below.

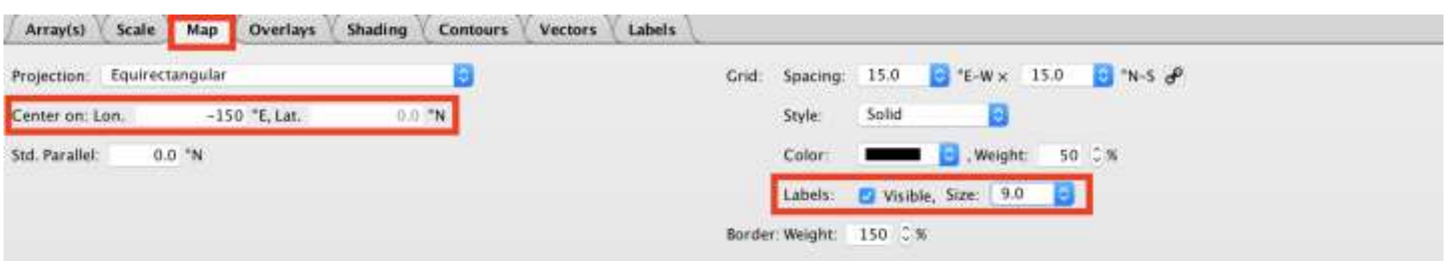
Step 11. Next, change the Color Table to **CB_RdBu.cpt** and then check the box for **Reverse colors**, as shown in the image below.

The map should now look like the map in the image below:

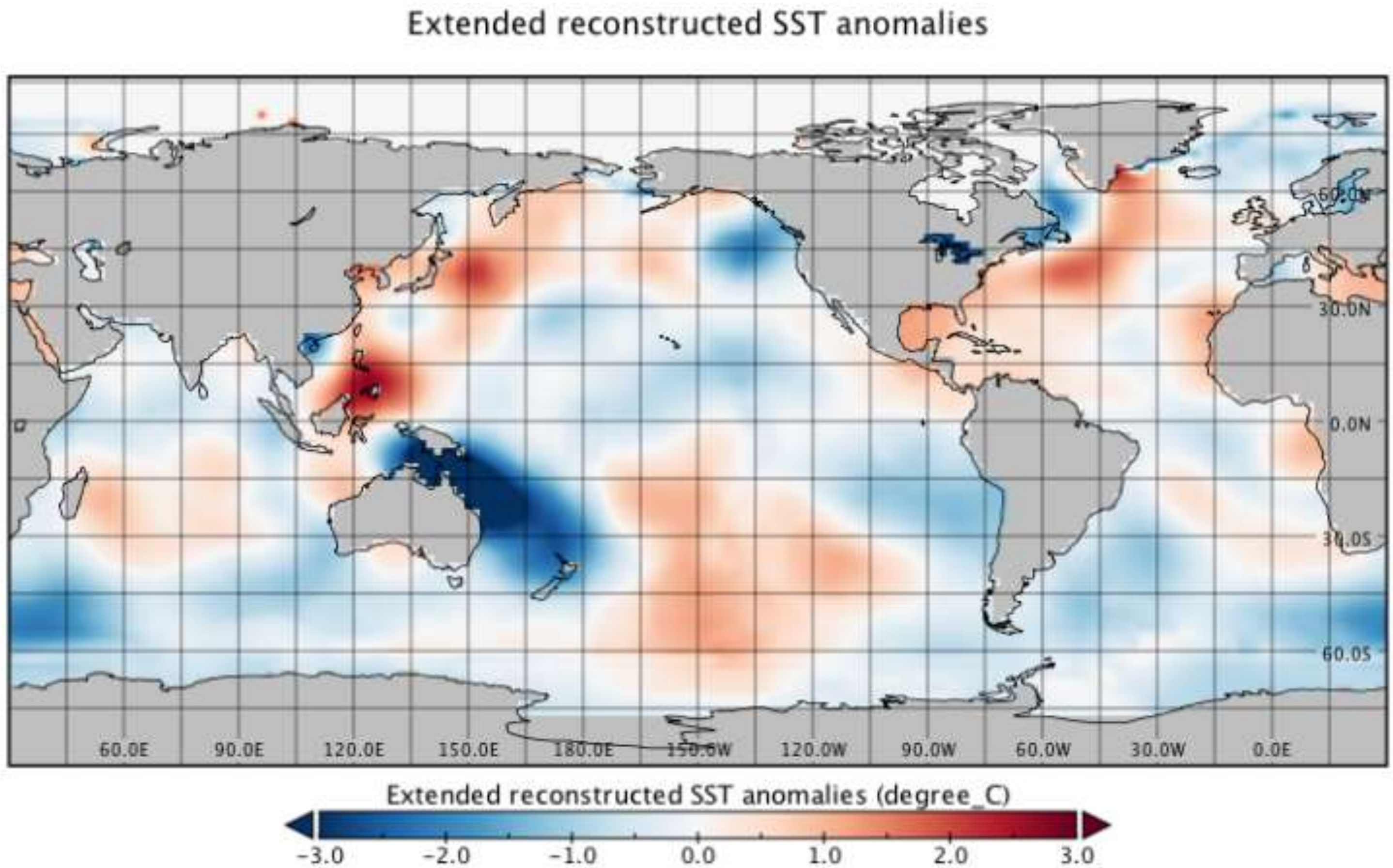


Step 12. The map is currently centered on 0˚ longitude. ENSO events take place in the equatorial Pacific Ocean, which should be the center of the map. To change the longitude the map is centered on, click on the **Map** tab near the bottom of Panoply, and then change the longitude to **-150 ˚E**, as shown in the image below.

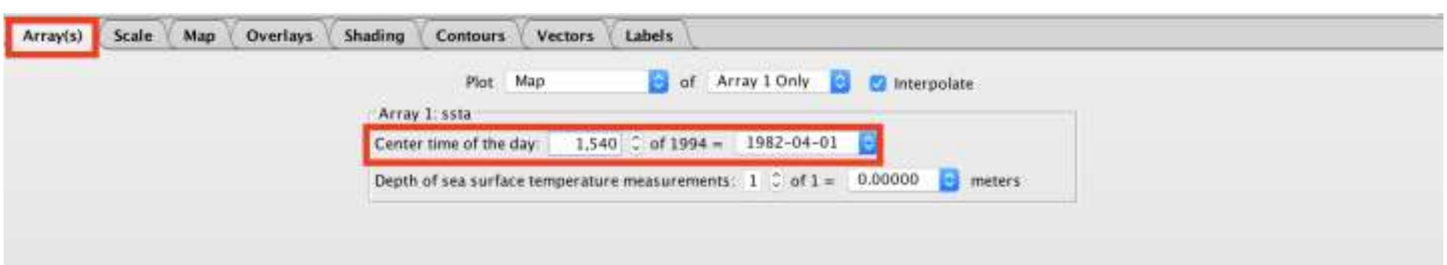
Also, check off the box for **Labels** and change the **Size** to **9.0** to display the latitude and longitude labels on the map, as shown in the image below.



This centers the map on 150˚W (-150˚E) longitude. Your map should now look like the map in the image below.



Step 13. Click on the Array(s) tab near the bottom of Panoply and change the **Center time of the day** to 1,540 to represent April 1982 (1982-04-01), as shown in the image below.



Step 14. Click on the up arrow to slowly change the **Center time of the day** from 1,540 (April 1982) to 1,554 (June 1983). Observe the sea surface temperature anomalies in the eastern equatorial Pacific Ocean.

Q4. Describe the type of sea surface temperature anomalies in the **eastern** equatorial Pacific Ocean between April 1982 and June 1983.

The sea surface temperature anomalies were positive.

Q5. How did the sea surface temperature anomalies change in the **eastern** equatorial Pacific Ocean between April 1982 and June 1983?

Between April 1982 and June 1983, the positive sea surface temperature anomalies increased both in value and area extending from the northwest coast of South America westward to the middle of the equatorial Pacific Ocean.

Q6. The El Niño Southern Oscillation (ENSO) has three phases: El Niño, La Niña, and neutral. An El Niño event took place between 1982 and 1983. Based on your answers to Q1 – Q4 and your observations of the sea surface temperature anomalies in Panoply, define an El Niño event.

An El Niño event is when the sea surface temperature anomalies in the eastern equatorial Pacific Ocean are positive, indicating warmer than normal sea surface temperatures.

Step 15. Change the time slice to 1,634 to represent February 1990 and observe the sea surface temperatures in the equatorial Pacific Ocean.

Q7. How are the sea surface temperature anomalies in the equatorial Pacific Ocean in February 1990 different from the sea surface temperature anomalies from April 1982 to June 1983?

The sea surface temperature anomalies in the equatorial Pacific Ocean in February 1990 are less positive than the anomalies between April 1982 and June 1983.

Q8. During February 1990, an El Niño event did not occur. Based on this information, change your definition of an El Niño event from Q5 and then explain your changes. If your answer does not change, explain why your answer remains the same based on the data.

Definition: **An El Niño event occurs when the sea surface temperature anomaly in the eastern equatorial Pacific Ocean is greater than 0.5˚C. The sea surface temperature anomaly must be greater than a specific threshold to be considered an El Niño event; small positive anomalies are not enough to signal an El Niño.**

Explanation: **Answers will vary based on original definition of El Niño.**

Step 16. Change the time slice to 1,743 to represent March 1999. Then, click on the up arrow to slowly change the time from 1,742 (March 1999) to 1,754 (February 2000). Observe the sea surface temperature anomalies in the eastern equatorial Pacific Ocean.

Q9. Describe the type of sea surface temperature anomalies in the **eastern** equatorial Pacific Ocean between March 1999 and February 2000.

The sea surface temperature anomalies were negative.

Q10. How did the sea surface temperature anomalies change in the **eastern** equatorial Pacific Ocean between March 1999 and February 2000?

Between April 1982 and June 1983, the negative sea surface temperature anomalies decreased, but increased in area extending from the northwest coast of South America westward to the middle of the equatorial Pacific Ocean.

Q11. The El Niño Southern Oscillation (ENSO) has three phases: El Niño, La Niña, and neutral. A La Niña event took place between 1999 and 2000. Based on your answers to Q8 - Q11 and your observations of the sea surface temperature anomalies in Panoply, define a La Niña event.

A La Niña event is when the sea surface temperature anomalies in the eastern equatorial Pacific Ocean are negative, indicating colder than normal sea surface temperatures.

Step 17. Change the time slice to 1777 to represent January 2002 and observe the sea surface temperatures in the equatorial Pacific Ocean.

Q12. How are the sea surface temperature anomalies in the equatorial Pacific Ocean in January 2002 different from the sea surface temperature anomalies from March 1999 to February 2000?

The sea surface temperature anomalies are negative, but less negative than the anomalies between March 1999 and February 2000.

Q13. During January 2002, a La Niña event did not occur. Based on this information, change your definition of a La Niña event from Q12 and then explain your changes. If your answer does not change, explain why your answer remains the same based on the data.

Definition: **A La Niña event occurs when the sea surface temperature anomaly in the eastern equatorial Pacific Ocean is less than -0.5˚C. The sea surface temperature anomaly must be less than a specific threshold to be considered a La Niña event; small negative anomalies are not enough to signal an El Niño.**

Explanation: **Answers will vary based on original definition of La Niña.**

Q14. Change the time slice back to 1,634 to represent February 1990 and then change the time slice back to 1,777 to represent January 2002. Both of these months represent ENSO neutral events, which means neither an El Niño nor La Niña event was occurring.

Describe the evidence provided by the sea surface temperature anomalies in the equatorial Pacific Ocean that ENSO neutral events were occurring during these months.

During the ENSO neutral months of February 1990 and January 2002, the sea surface temperature anomalies were only slightly positive and negative, signaling only a small departure from the average. El Niño and La Niña events occur when the anomalies are more positive or more negative.

Q15. Based on your findings from this activity, explain how climatologists use sea surface temperature anomalies in the equatorial Pacific Ocean to classify an El Niño event.

El Niño events are classified when the sea surface temperature anomalies in the eastern equatorial Pacific Ocean are 0.5˚C or more above normal (higher positive sea surface temperature anomaly).

Q16. Based on your findings from this activity, explain how climatologists use sea surface temperature anomalies in the equatorial Pacific Ocean to classify a La Niña event.

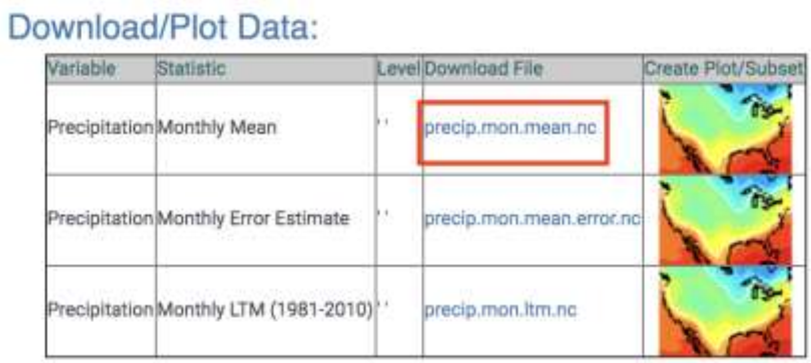
La Niña events are classified when the sea surface temperature anomalies in the eastern equatorial Pacific Ocean are 0.5˚C or more below normal (higher negative sea surface temperature anomaly).

EXPLORE – Part 2: Precipitation

Step 1. We will now explore the relationship between ENSO and precipitation. Go to this link to download precipitation data from Global Precipitation Climatology Project and look for the section titled **Download/Plot Data**. GPCP Precipitation data provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, from their Web site at https://psl.noaa.gov/

Step 2. Click on **precip.mon.mean.nc** as shown in the image below to download average monthly precipitation data. This dataset contains average monthly precipitation for every month from January 1979 to May 2020 for a total of 497 time slices, one for each month.

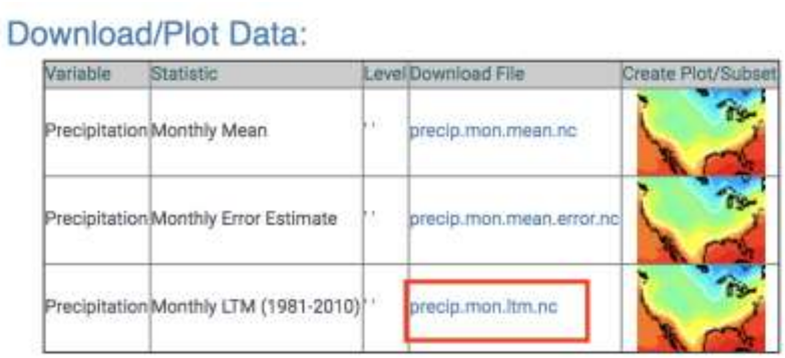
Note: The most recent time slice is May 2020 based on the time this activity was created. The dataset will contain more time slices as more time passes.


Download/Plot Data:

Variable	Statistic	Level	Download File	Create Plot/Subset
Precipitation	Monthly Mean		precip.mon.mean.nc	
Precipitation	Monthly Error Estimate		precip.mon.mean.error.nc	
Precipitation	Monthly LTM (1981-2010)		precip.mon.ltm.nc	

Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **precip.mon.mean.nc.** For simplicity, change the name of the file to **precip.nc** by right-clicking on the dataset and selecting "rename".

Step 3. Next, click on **precip.mon.ltm.nc** as shown in the image below to download the long-term monthly average precipitation. This dataset contains the average precipitation between 1981 and 2010 for the month of January, February, March, etc. This means this dataset contains only 12 time slices, one for each month.

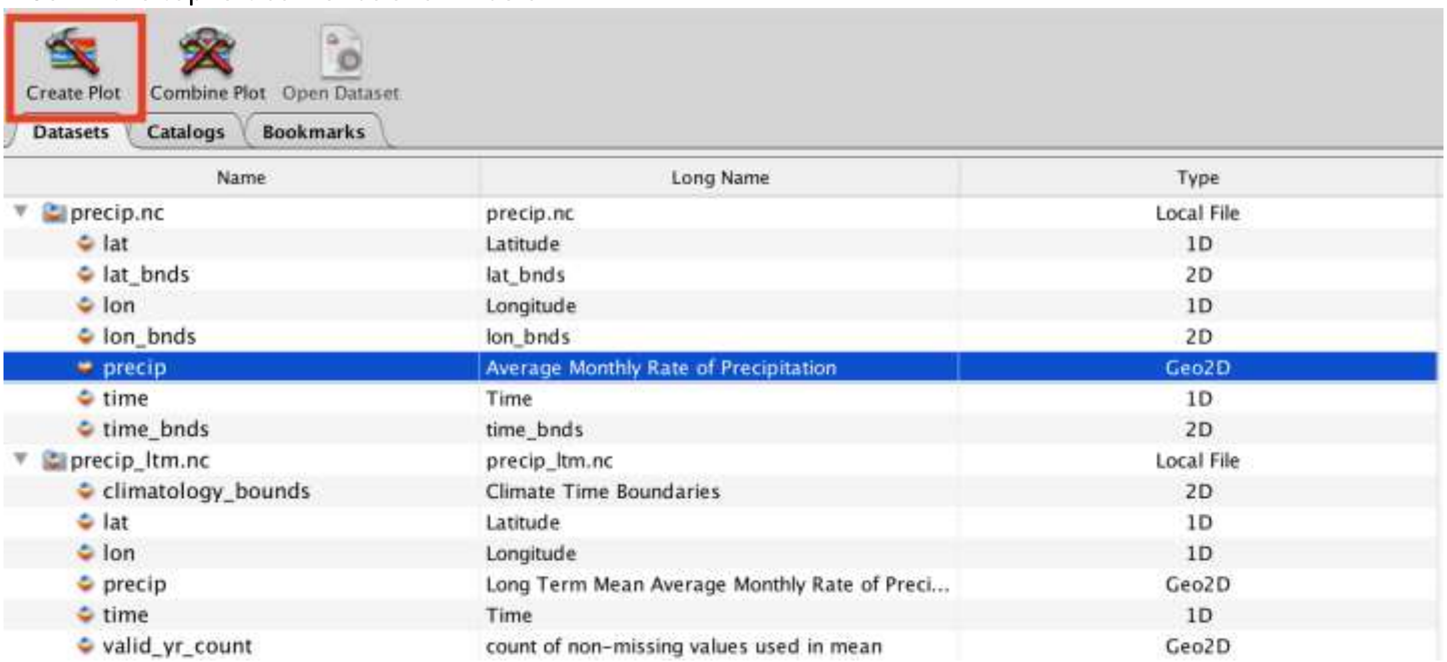

Download/Plot Data:

Variable	Statistic	Level	Download File	Create Plot/Subset
Precipitation	Monthly Mean		precip.mon.mean.nc	
Precipitation	Monthly Error Estimate		precip.mon.mean.error.nc	
Precipitation	Monthly LTM (1981-2010)		precip.mon.ltm.nc	

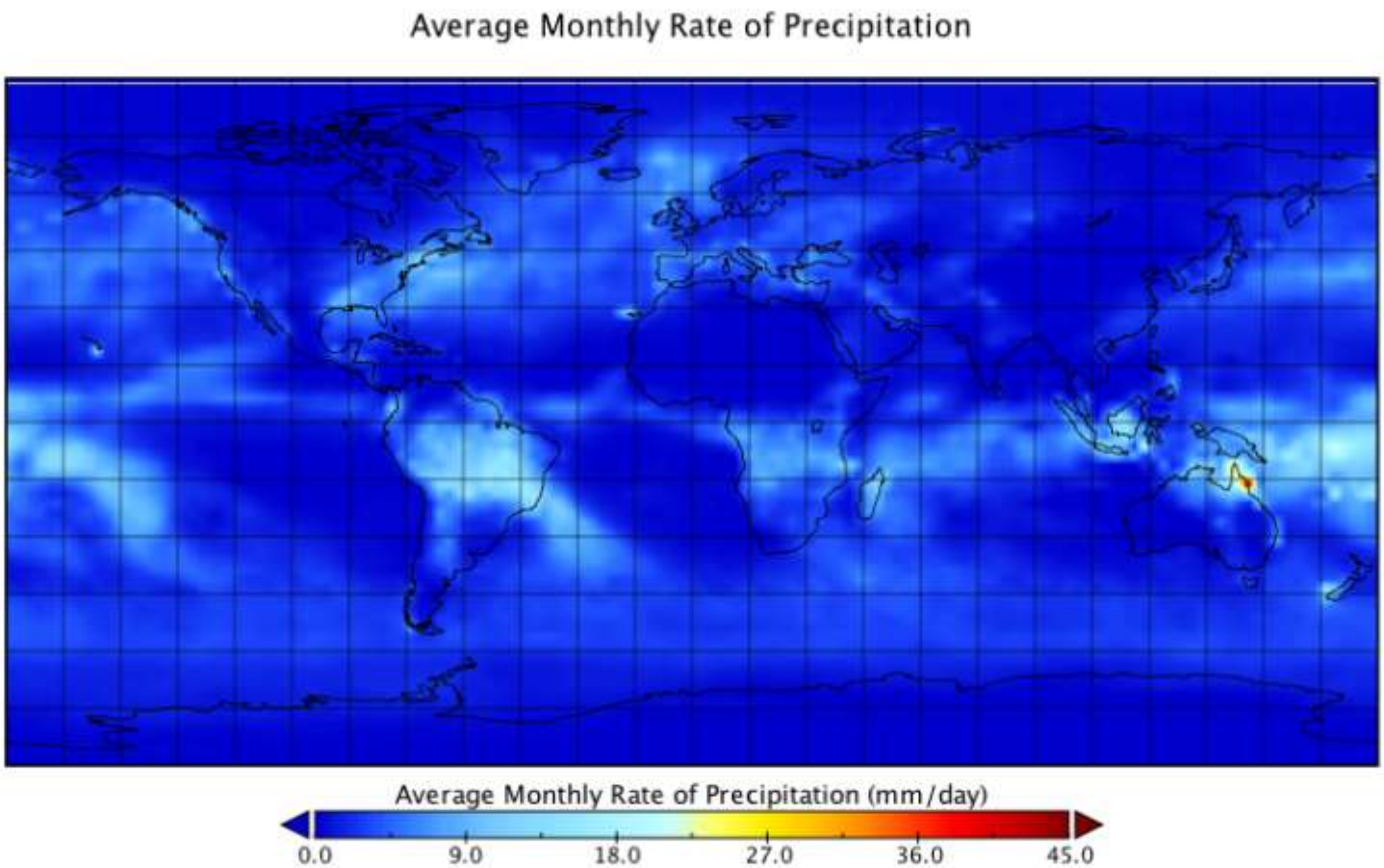
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **precip.mon.ltm.nc.** For simplicity, change the name of the file to **precip_ltm.nc** by right-clicking on the dataset and selecting “rename”.

Step 4. Open the **precip.nc** and **precip_ltm.nc** datasets in Panoply.

Step 5. In Panoply, go to the **precip.nc** dataset and click on the variable titled **“precip”** and then click **“Create Plot”** in the top left corner as shown below:

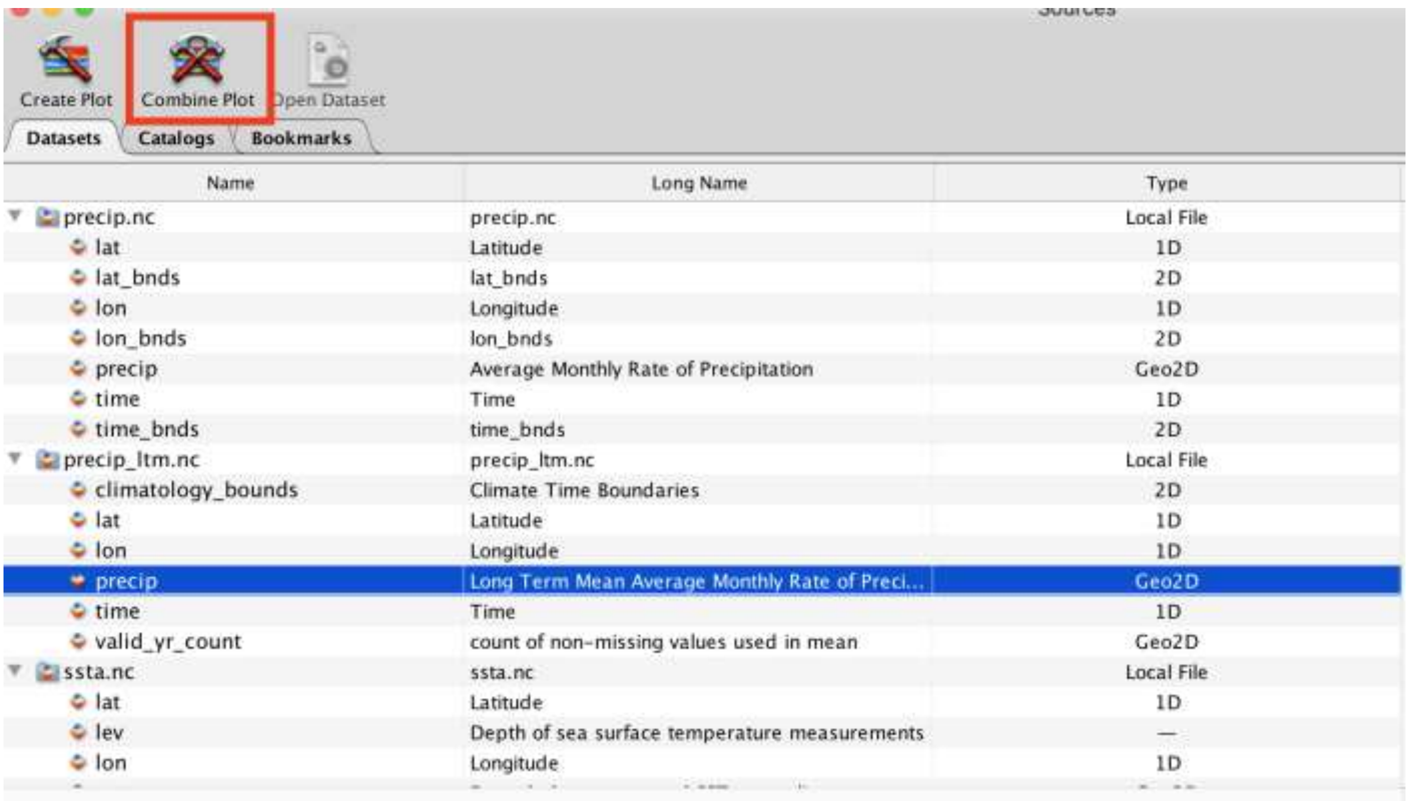


When prompted, click **Create** again and you should see a map that looks like the following:

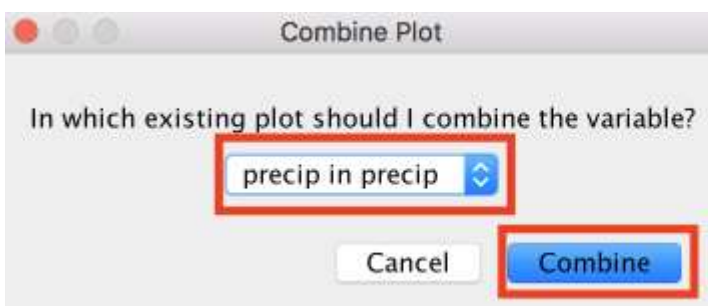


Step 6. Go back to the main window of Panoply and under the **precip_ltm.nc** dataset, click on the **precip** variable as shown in the image below.

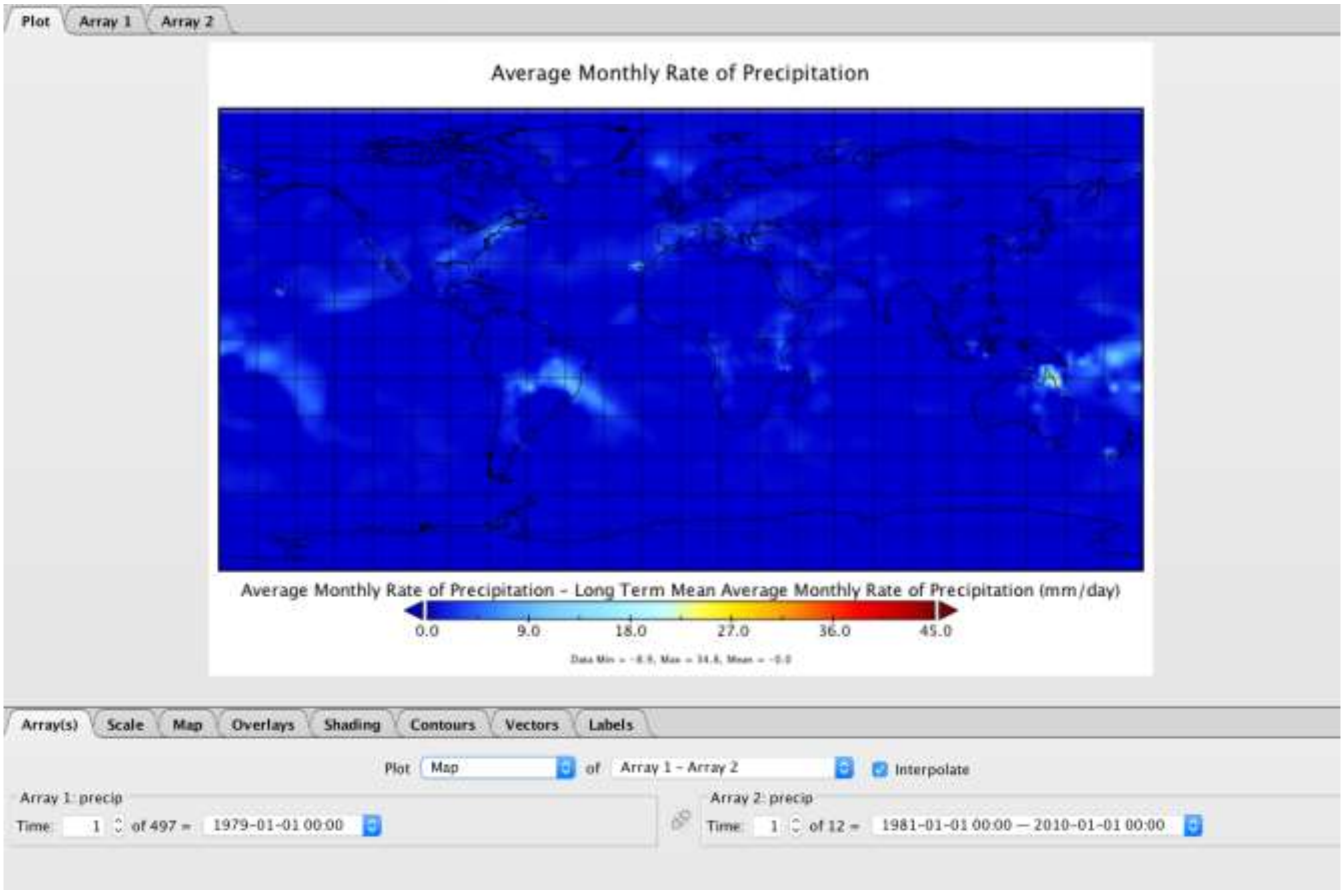
Then, click on **Combine Plot** as shown in the image below.



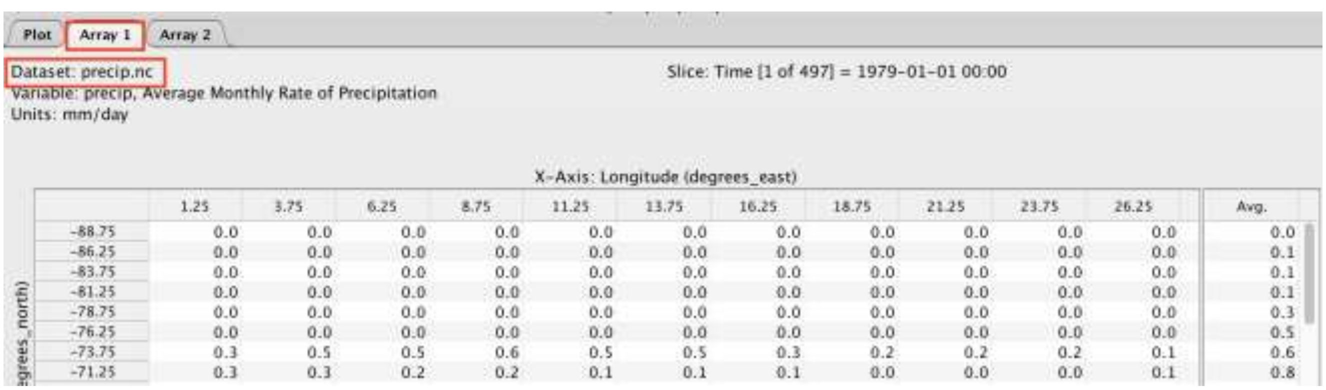
Step 7. Make sure you have **precip in precip** selected, and then click **Combine**, as shown in the image below.



These actions allow for both the **precip.nc** and **precip_ltm.nc** data to both be viewable in the plot window of Panoply. You should now see a map that looks like the following:

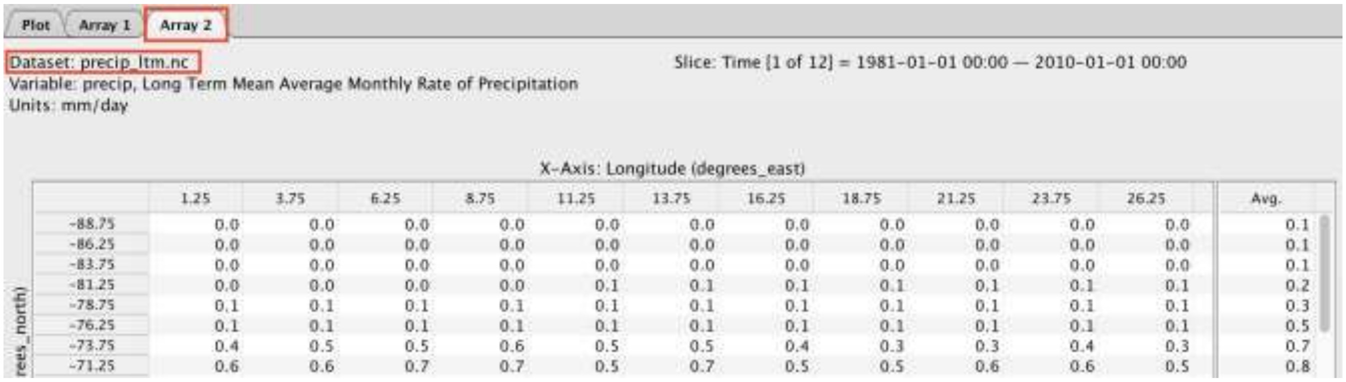


Step 8. Near the top of Panoply, click on the **Array 1** tab and you should see that the dataset in Array 1 is **precip.nc**. This is shown in the image below.



	1.25	3.75	6.25	8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	Avg.
-88.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-86.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-83.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-81.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-78.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
-76.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
-73.75	0.3	0.5	0.5	0.6	0.5	0.5	0.3	0.2	0.2	0.2	0.1	0.6
-71.25	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.8

Step 9. Next, click on **Array 2** to ensure that the dataset in this array **is precip_ltm.nc**, as shown below.



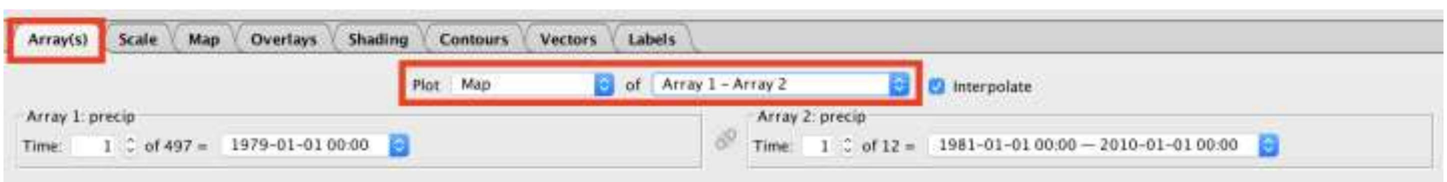
	1.25	3.75	6.25	8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	Avg.
-88.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-86.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-83.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-81.25	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
-78.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
-76.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5
-73.75	0.4	0.5	0.5	0.6	0.5	0.5	0.4	0.3	0.3	0.4	0.3	0.7
-71.25	0.6	0.6	0.7	0.7	0.5	0.7	0.5	0.5	0.6	0.6	0.5	0.8

Step 10. Our purpose of combining the **precip.nc** and **precip_ltm.nc** data is to create a dataset that represents the precipitation anomaly. To calculate an anomaly, the long-term average (**precip.ltm.nc**) needs to be subtracted from the monthly data (**precip.nc**). This calculation is shown below:

Precipitation Anomaly = precip.nc – precip_ltm.nc

Now that the data is combined, this calculation can be done directly in Panoply.

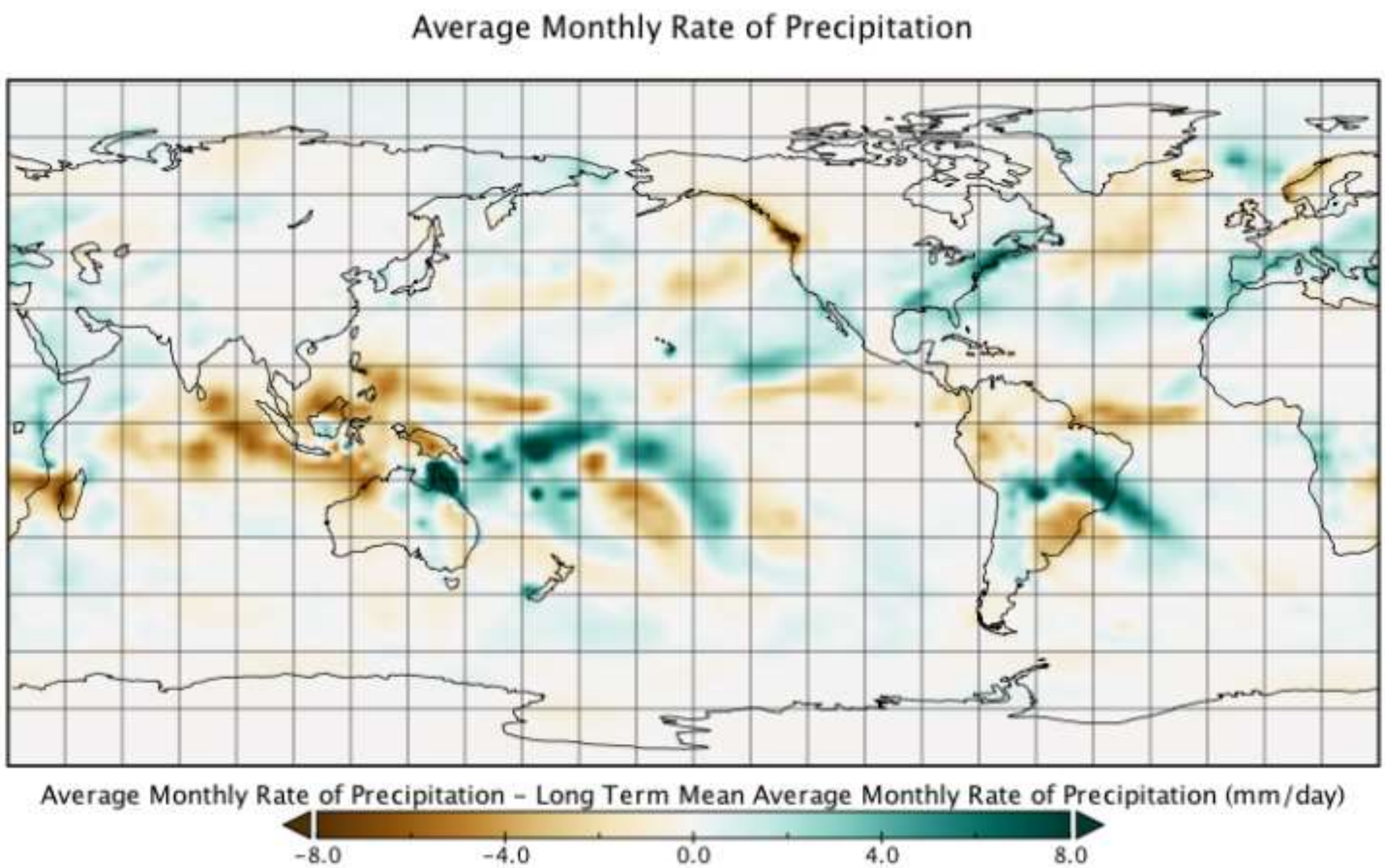
Step 11. Click on the **Plot** tab near the top left of Panoply. Then, click on the **Array(s)** tab near the bottom of Panoply. Make sure that Array 1 – Array 2 is selected, as shown in the image below. This setting means Panoply is creating a map based on the subtraction of Array 1 – Array 2, which is **precip.nc** – **precip_ltm.nc**.



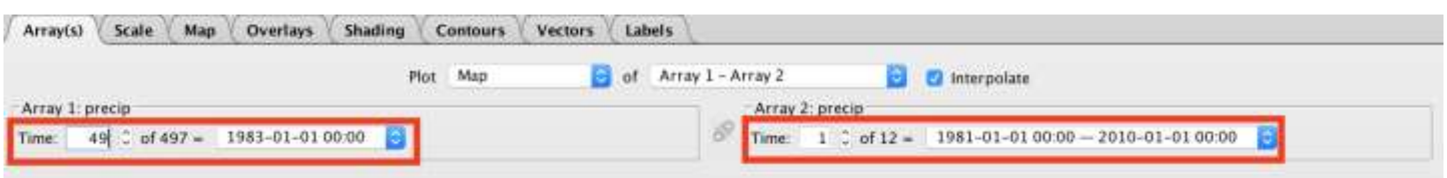
Step 12. Go to the **Map** tab near the bottom of Panoply and change the settings to center the map on 150˚W longitude by typing in **-150˚E**.

Next, go to the **Scale** tab and change the scale range so the **Min** is **-8** and the **Max** is **8**. Change the **Divisions, Major** to **4** and then change the **Color Table** to **CB_BrBG.cpt.** This is all displayed in the image below.

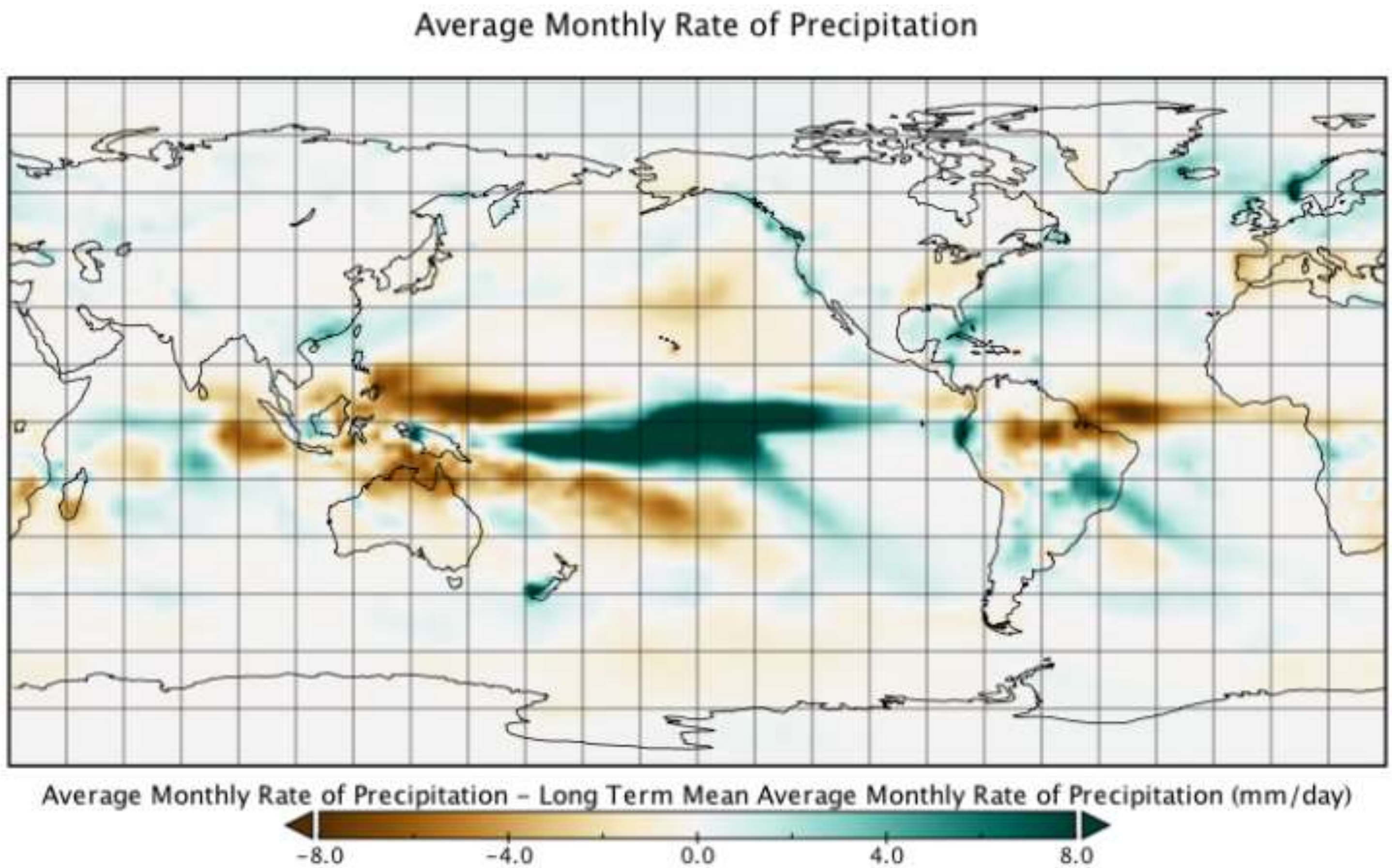
Step 13. Your map should now look like the map below:



Step 14. Go to the **Array(s)** tab near the bottom of Panoply and change the time slice for Array 1 to **49** to represent the average precipitation during January 1983 (1983-01-01 00:00), a time during an El Niño event. Then, change the time slice for Array 2 to **1**, to represent the long-term monthly average for the month of January. These settings result in Panoply calculating the precipitation anomaly for the month of January 1983. The image below shows these settings.



Step 15. Your map should now look like the map below:



Q1. What does a positive precipitation anomaly mean?

A positive precipitation anomaly means the amount of precipitation for a given location is greater than average.

Q2. Describe the general location on the map where there are the greatest positive precipitation anomalies.

The general location with the greatest positive precipitation anomalies is in the central to eastern equatorial Pacific Ocean. There is also a large positive precipitation anomaly on the northwest coast of South America.

Q3. What does a negative precipitation anomaly mean?

A negative precipitation anomaly means the amount of precipitation for a given location is lower than average.

Q4. Describe the general location on the map where there are the greatest negative precipitation anomalies.

The general location with the greatest negative precipitation anomalies is in the western equatorial Pacific Ocean near Southeast Asia and northern Australia. There are also large negative precipitation anomalies near the northeast coast of South America.

Step 16. Change the time for Array 1 to **230** and the time for Array 2 to **2** to represent precipitation anomalies during February 1998, a time during another El Niño event.

Q5. ***Circle one option below.*** In general, is the location with the greatest **positive** precipitation anomalies for the El Niño event in February 1998 similar to or different from the location for the El Niño event in December 1982?

Similar ***Different***

Q6. ***Circle one option below.*** In general, is the location with the greatest **negative** precipitation anomalies for the El Niño event in February 1998 similar to or different from the location for the El Niño event in December 1982?

Similar ***Different***

Step 17. Change the time for Array 1 to **444** and the time for Array 2 to **12** to represent precipitation anomalies during December 2015, a time during another El Niño event.

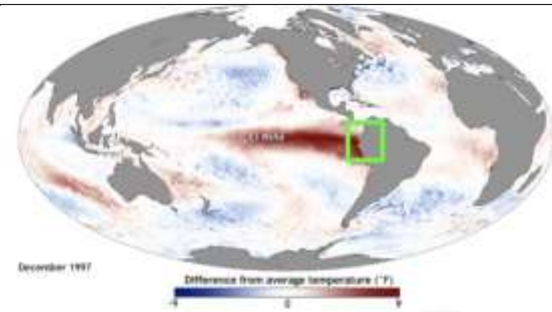
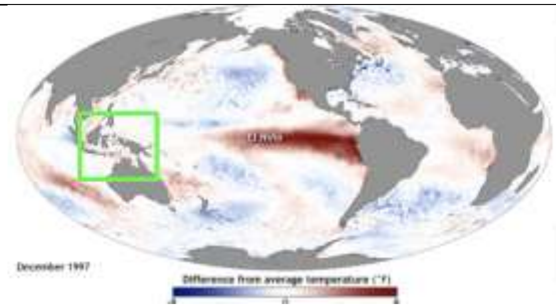
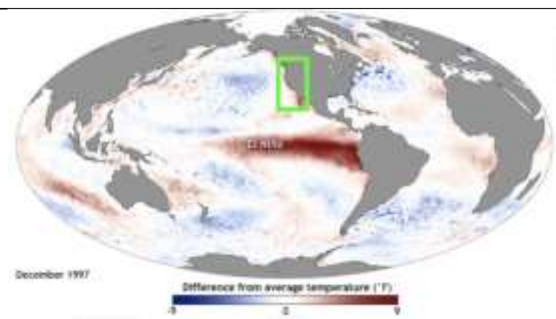
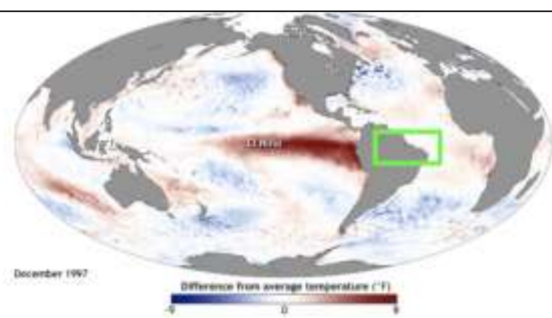
Q7. ***Circle one option below.*** In general, is the location with the greatest **positive** precipitation anomalies for the El Niño event in December 2015 similar to or different from the location for the El Niño event in December 1982 and February 1998?

Similar ***Different***

Q8. ***Circle one option below.*** In general, is the location with the greatest **negative** precipitation anomalies for the El Niño event in December 2015 similar to or different from the location for the El Niño event in December 1982 and February 1998?

Similar ***Different***

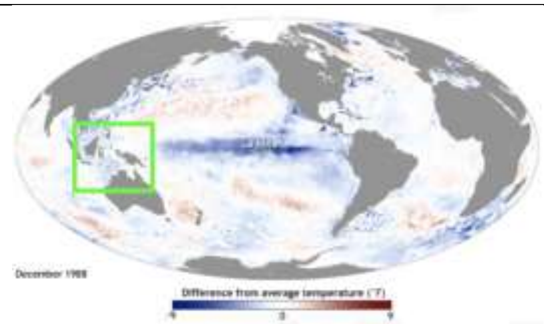
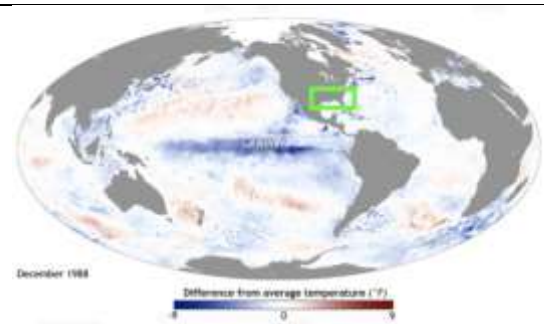
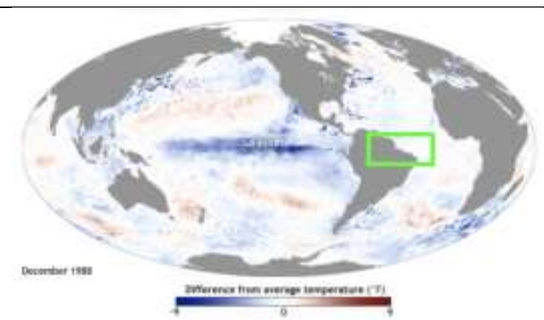
Q9. The data table below is similar to the one in the previous ENGAGE activity. After reviewing the precipitation anomalies for the winter months during three different El Niño events, describe whether each location experiences more or less precipitation than normal in the winter during El Niño events.

Location	Map	El Niño Impact on Winter Precipitation
West coast of South America		**The northwest coast of South America experiences above normal precipitation (positive precipitation anomalies).**
Southeast Asia and Australia		**Southeast Asia and Australia experiences below normal precipitation (negative precipitation anomalies).**
West Coast of North America		**The west coast of North America experiences above slightly above normal precipitation (positive precipitation anomalies).**
East Coast of South America		**The East Coast of South America experiences below normal precipitation (negative precipitation anomalies).**

Step 18. We will now explore precipitation anomalies in winter months during La Niña events, which is referred to as the cold phase of ENSO. Using Panoply, analyze the precipitation anomalies for the following three La Niña events:

- **December 1988** (Change Array 1 to **120** and Array 2 to **12**)
- **December 1999** (Change Array 1 to **252** and Array 2 to **12**)
- **December 2010** (Change Array 1 to **384** and Array 2 to **12**)

Q10. After reviewing the precipitation anomalies for the winter months during three different La Niña events, describe whether each location experiences more or less precipitation than normal in the winter during La Niña events.

Location	Map	La Niña Impact on Winter Precipitation
Southeast Asia and Australia		**Southeast Asia and Australia experiences above normal precipitation (positive precipitation anomalies).**
Southeast Coast of North America		**The southeast coast of North America experiences below normal precipitation (negative precipitation anomalies).**
Northeast Coast of South America		**The northeast coast of South America experiences above normal precipitation (positive precipitation anomalies).**

EXPLAIN

Step 1. The goal of our EXPLAIN activity is to be able to uncover why El Niño and La Niña events occur and lead to the temperature and precipitation anomalies observed.

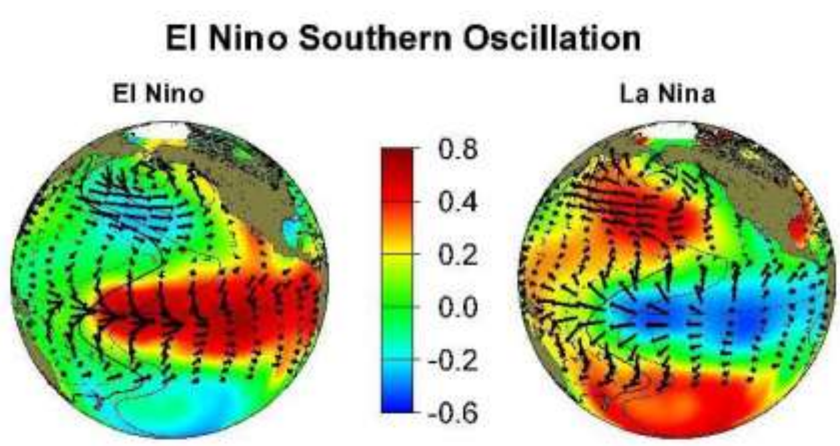
El Niño events are classified when the sea surface temperature anomalies in the eastern equatorial Pacific Ocean are 0.5˚C or greater for three consecutive months, while La Niña events are classified when the anomalies are -0.5˚C or less for three consecutive months.

Q1. What are the criteria for classifying an El Niño and La Niña event?

El Niño: **Sea surface temperature anomalies in the eastern equatorial Pacific Ocean are 0.5˚C or greater for three consecutive months.**

La Niña: **Sea surface temperature anomalies in the eastern equatorial Pacific Ocean are -0.5˚C or less for three consecutive months.**

One of the driving factors influencing ENSO events is the direction of the wind that results from the changing pressure in the eastern and western equatorial Pacific Ocean. The diagram below from NOAA, which can be accessed at this GLOBE resource, shows the varying wind speeds and directions associated with El Niño and La Niña events. The direction of the arrows correspond to the wind direction and the length of the arrow corresponds to the speed of the wind; the longer the arrow, the greater the windspeed. The maps are both centered on the equatorial Pacific Ocean.



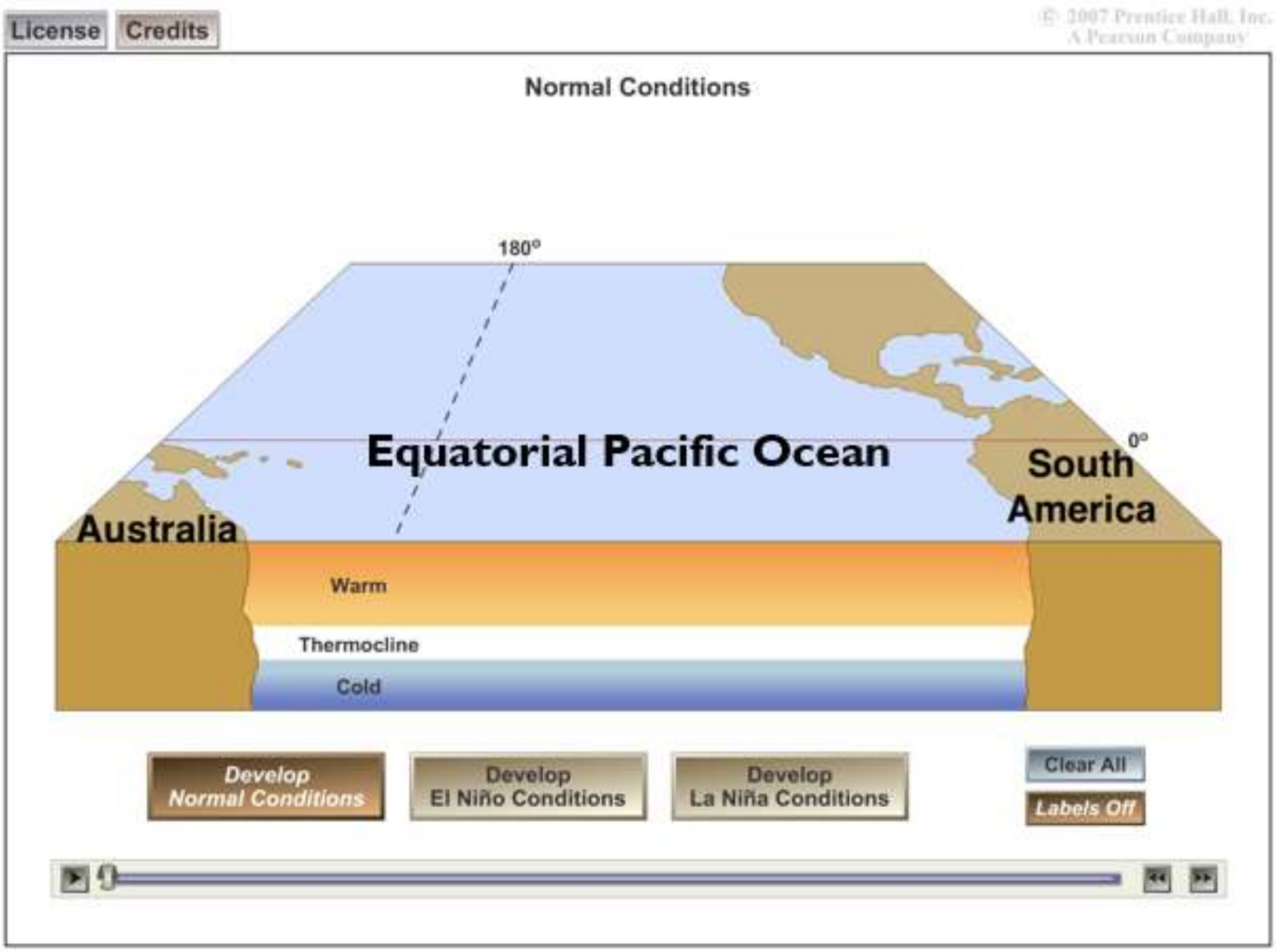
Q2. Based on the diagram above, compare the general windspeed and direction in the eastern equatorial Pacific Ocean during El Niño and La Niña events.

The winds during an El Niño event are flowing from west to east, while the winds are flowing from east to west during a La Niña event. The wind speed during El Niño events are also weaker than the wind speeds during La Niña events.

Step 2. Go to this link to view an ENSO simulation. You will be brought to a page with three different animations: one for Normal Conditions, one for El Niño Conditions, and another for La Niña Conditions. The El Niño Southern Oscillation (ENSO) has three phases; a normal phase, a warm phase (El Niño), and a cold phase (La Niña).

Through the simulation, you will first investigate the changes in sea surface temperature, precipitation, and air pressure. Then, you will be able to explain why those changes occur based on the changing wind patterns.

Step 3. Make sure your animation is set to Normal Conditions, as shown in the screenshot below.



***Note the addition of labels for South America and Australia in the screenshot above to help identify the landmasses on either side of the equatorial Pacific Ocean. Additionally, the thermocline is defined as the boundary between warmer water near the surface and colder water below.**

Step 4. Click the play button (triangle) in the bottom left corner of the animation to view atmospheric conditions during the Normal state of ENSO. Make sure the animation plays the entire way through.

Q3. After viewing the Normal Conditions animation, describe in general where the colder surface water is located.

Under normal conditions, the colder surface water is located in the eastern equatorial Pacific Ocean off the northwest coast of South America.

Q4. After viewing the Normal Conditions animation, describe where the high-pressure system is generally located.

Under normal conditions, the high pressure is generally located in the eastern equatorial Pacific Ocean off the northwest coast of South America.

Q5. How is this high pressure impacting the amount of precipitation of the region that it is in?

The high pressure reduces the amount of precipitation in that region in the eastern equatorial Pacific Ocean.

Q6. After viewing the Normal Conditions animation, describe where the warmer surface water is generally located.

Under normal conditions, the warmer surface water is located in the western equatorial Pacific Ocean.

Q7. After viewing the Normal Conditions animation, describe where the low-pressure system is generally located.

Under normal conditions, the low pressure is generally located in the western equatorial Pacific Ocean.

Q8. How is this low pressure impacting the amount of precipitation of the region that it is in?

The low pressure increases the amount of precipitation in that region in the western equatorial Pacific Ocean.

Step 5. Near the bottom of the animation, click on **Develop El Niño Conditions** and then press play to see how the ocean and atmosphere change due to El Niño conditions. Be sure to play this animation all the way to the end to see the entire development of El Niño conditions.

Q9. After viewing the El Niño Conditions animation, describe how the sea surface temperature changed in the eastern equatorial Pacific Ocean (near South America).

SST in eastern equatorial Pacific Ocean (near South America): **The SST increased in the equatorial Pacific Ocean**

Q10. After viewing the El Niño Conditions animation, describe how the pressure changed over the eastern equatorial Pacific Ocean (near South America) and the western equatorial Pacific Ocean (near Australia).

Pressure in eastern equatorial Pacific Ocean (near South America): **The pressure decreased in the eastern equatorial Pacific Ocean**

Pressure in western equatorial Pacific Ocean (near Australia): **The pressure increased in the western equatorial Pacific Ocean**

Q11. After viewing the El Niño Conditions animation, describe how the amount of precipitation changed over the eastern equatorial Pacific Ocean (near South America) and the western equatorial Pacific Ocean (near Australia).

Precipitation in eastern equatorial Pacific Ocean (near South America): **The amount of precipitation increased in the eastern equatorial Pacific Ocean**

Precipitation in western equatorial Pacific Ocean (near Australia): **The amount of precipitation decreased in the western equatorial Pacific Ocean**

Step 6. Refresh the animation and click **Develop Normal Conditions** and watch the entire animation. Then, click **Develop El Niño Conditions** and watch the entire animation. This time when you play the animations, pay attention to the changes in wind patterns and surface ocean currents as conditions transition from Normal to El Niño conditions.

Note: The solid black arrows represent the movement of surface ocean currents.

Note: The red arrows show the direction of surface winds.

Q12. As El Niño conditions develop, describe how the movement of the surface ocean currents changed in the equatorial Pacific Ocean.

As El Niño conditions developed, the surface ocean currents reversed direction and started to travel from the western equatorial Pacific Ocean toward the eastern equatorial Pacific Ocean.

Q13. As El Niño conditions develop, describe how the direction of the surface winds changed in the equatorial Pacific Ocean.

As El Niño conditions developed, the surface winds reversed direction and started to travel from the western equatorial Pacific Ocean toward the eastern equatorial Pacific Ocean.

Q14. As El Niño conditions develop, what happens to the temperature of the surface ocean water along the northwest coast of South America (eastern equatorial Pacific Ocean)?

As El Niño conditions developed, the surface ocean water temperature along the northwest coast of South America increased.

Why does the temperature change water in this region?

As the surface winds and ocean currents reversed direction to flow from the western equatorial Pacific Ocean toward the eastern equatorial Pacific Ocean, the warm water from the western equatorial Pacific Ocean was transported to the eastern equatorial Pacific Ocean. This movement of warm surface ocean water increased the sea surface temperature in the eastern equatorial Pacific Ocean.

Q15. As El Niño conditions develop, what type of pressure develops in the eastern Pacific Ocean (near the northwest coast of South America). Then, explain why there was a change in pressure.

Pressure in eastern equatorial Pacific Ocean (near South America): **Low pressure**

Explanation: **The warmer water in the eastern equatorial Pacific Ocean caused warm air to rise, resulting in clouds and low pressure to develop.**

Q16. As El Niño conditions develop, describe what happens to the amount of precipitation in the eastern Pacific Ocean (near the northwest coast of South America) and the western equatorial Pacific Ocean (near Australia). For each region, also explain why there was a change in the amount of precipitation.

Precipitation in eastern equatorial Pacific Ocean (near South America): **The amount of precipitation increases**

Explanation: **The amount of precipitation increases because the warm water that moved in lowered the air pressure, leading to rising air, cloud formation, and rain.**

Precipitation in western equatorial Pacific Ocean (near Australia): **The amount of precipitation decreases**

Explanation: **The amount of precipitation decreases because of a high-pressure system that developed in the western equatorial Pacific Ocean.**

Q17. Write a brief summary to explain why there is more precipitation in the eastern equatorial Pacific Ocean and less precipitation in the western equatorial Pacific Ocean during El Niño events. Your answer should include information about the surface ocean currents, surface winds, air pressure, and sea surface temperature.

During an El Niño event, the surface winds and ocean currents reverse direction and instead of flowing from east to west, they flow from west to east. This causes the warm surface ocean water from the western equatorial Pacific Ocean to move eastward, increasing the sea surface temperature in the eastern

equatorial Pacific Ocean. This leads to the development of a low-pressure system, ultimately resulting in increased cloud formation and precipitation in the eastern equatorial Pacific Ocean.

7. Near the bottom of the animation, click on **Develop La Niña Conditions** and then press play to see how the ocean and atmosphere change due to La Niña conditions. Be sure to play this animation all the way to the end to see the entire development of La Niña conditions.

Q18. Write a brief summary to explain why there is less precipitation in the eastern equatorial Pacific Ocean and more precipitation in the western equatorial Pacific Ocean during La Niña events. Your answer should include information about the surface ocean currents, surface winds, air pressure, and sea surface temperature.

During a La Niña event, the east to west flowing surface ocean currents and surface winds increase in strength, causing the upwelling of cold water along the west coast of South America. This decreases the sea surface temperature of the eastern equatorial Pacific Ocean, and in turn strengthens the high-pressure system in the region. The high-pressure system reduces cloud formation and the amount of precipitation in the region.

ELABORATE

While many locations in the middle and high latitudes experience seasons influenced mostly by temperature, many tropical locations around the world experience a wet and a dry season. The Amazon located in the northern region of South America experiences a wet and a dry season. Although it can vary from location to location, the dry season in the Amazon corresponds with the Southern Hemisphere winter, which takes place from about June to November. On the other hand, the wet season corresponds with the Northern Hemisphere winter, which takes place from about December to April.

Wildfires in the Amazon usually increase during the dry season months. However, the number of wildfires during the 2016 dry season were higher than the amount from previous years. It is believed that there was an increase due to a lower amount of rainfall in the preceding wet season from December 2015 to April 2016.

Your task is to determine if there is a relationship between ENSO and the increase in wildfires in the Amazon in 2016. Complete the tasks below and then answer the summary question.

- Go to this link to access the Mapping the Amazon resource from the NASA Earth Observatory to view a map that shows the location of the Amazon and its extent within South America.
- Analyze the sea surface temperature anomaly data in Panoply to determine the ENSO phase during the months preceding the 2016 Amazon dry season. Use the instructions from EXPLORE #1 as a guide.
- Analyze the precipitation anomaly data in Panoply to determine how precipitation in the Amazon region was impacted during the months preceding the 2016 Amazon dry season. Use the instructions from EXPLORE #2 as a guide.

Question: Based on your knowledge of ENSO and the sea surface temperature and precipitation anomaly data, identify whether an El Niño, La Niña, or ENSO neutral (normal phase) event took place and then explain how this ENSO phase resulted in the large-scale wildfire outbreak in the Amazon in 2016.

During the months preceding the 2016 dry season there was an El Niño event due to the anomalously high sea surface temperatures in the eastern equatorial Pacific Ocean. According to the precipitation anomalies from December 2015 to April 2016, the El Niño event resulted in below average precipitation in many locations across the Amazon. This means the typical wet season experienced less precipitation than normal, leading to drier conditions. As the 2016 dry season approached, the ground was already drier than normal, escalating the warm and dry conditions that lead to wildfires.

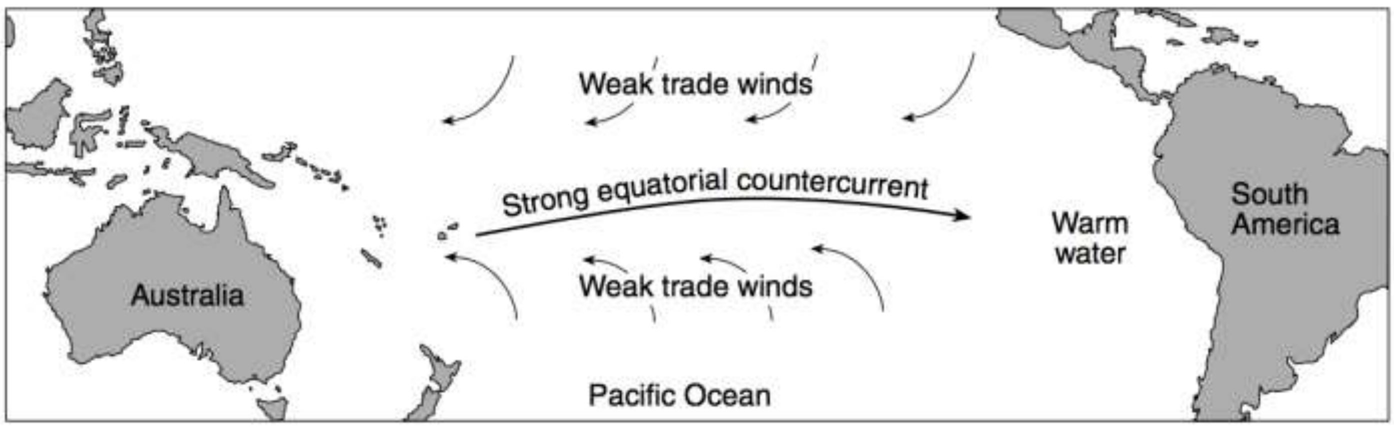
EVALUATE – Questions used and adapted from the New York State Earth Science Regents.

Q1. What is the name of the climate event that occurs when surface water in the eastern equatorial area of the Pacific Ocean becomes warmer than normal and may cause a change in global precipitation patterns?

El Niño event

Q2. The map below shows the weak trade winds and strong equatorial countercurrent in the Pacific Ocean during El Niño conditions. This causes warm surface ocean water to migrate eastward, lowering the atmospheric pressure above this warm water. The diagram and question are from the New York State Earth Science Regents.

El Niño Conditions



What are the most likely changes to atmospheric temperature and precipitation along the west coast of South America during El Niño conditions?

(1) lower temperatures and lower amounts of precipitation
(2) lower temperatures and higher amounts of precipitation
(3) higher temperatures and lower amounts of precipitation
(4) higher temperatures and higher amounts of precipitation

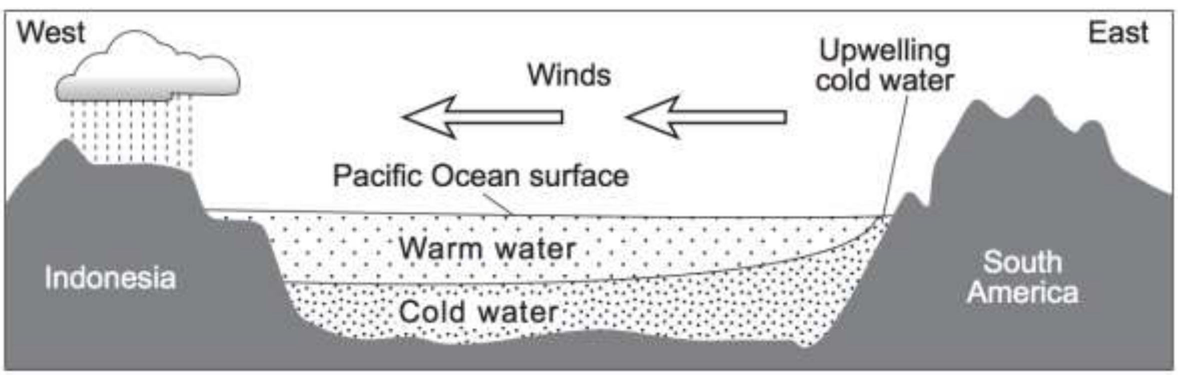
Base your answers to questions 3 through 5 on the passage and cross section below and on your knowledge of Earth science. The cross section represents a generalized region of the Pacific Ocean along the equator during normal (non-El Niño) conditions. The relative temperatures of the ocean water and the prevailing wind direction are indicated.

El Niño

Under normal Pacific Ocean conditions, strong winds blow from east to west along the equator. Surface ocean water piles up on the western part of the Pacific due to these winds. This allows deeper, colder ocean water on the eastern rim of the Pacific to be pulled up (upwelling) to replace the warmer surface water that was pushed westward.

During an El Niño event, these westward-blowing winds get weaker. As a result, warmer water does not get pushed westward as much, and colder water in the east is not pulled toward the surface. This creates warmer surface ocean water temperatures in the east, allowing the thunderstorms that normally occur at the equator in the western Pacific to move eastward. A strong El Niño is often associated with wet winters along the northwestern coast of South America and in the southeastern United States, and drier weather patterns in Southeast Asia (Indonesia) and Australia. The northeastern United States usually has warmer and drier winters in an El Niño year.

Normal Pacific Ocean Conditions (non-El Niño years)



(Not drawn to scale)

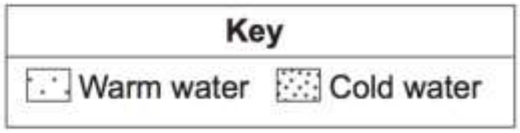
Q3. Compared to non-El Niño years, which climatic conditions exist near the equator on the western and eastern sides of the Pacific Ocean during an El Niño event?

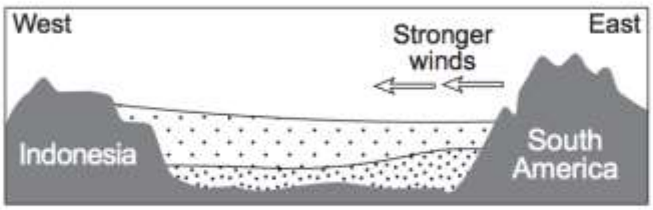
(1) The western Pacific is drier and the eastern Pacific is wetter.
(2) The western Pacific is wetter and the eastern Pacific is drier.
(3) The western and the eastern Pacific are both wetter.
(4) The western and the eastern Pacific are both drier.

Q4. During an El Niño year, winter climatic conditions in New York State will most likely be

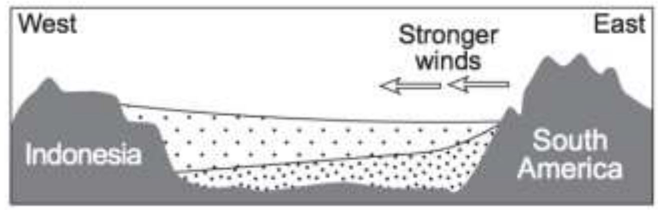
(1) colder and wetter (2) warmer and wetter (3) colder and drier **(4) warmer and drier**

Q5. **Choice #2** Which cross section best represents the changed wind conditions and Pacific Ocean temperatures during an El Niño event? [Diagrams are not drawn to scale.]

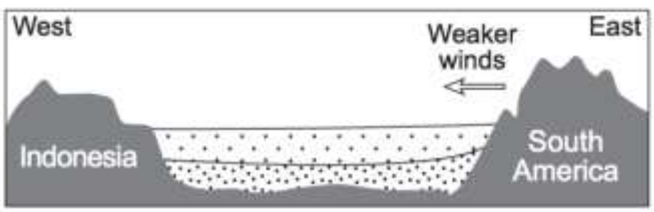




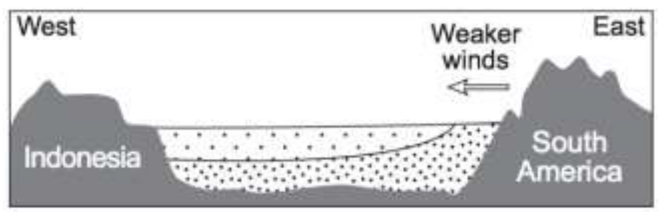
(1)



(3)



(2)



(4)

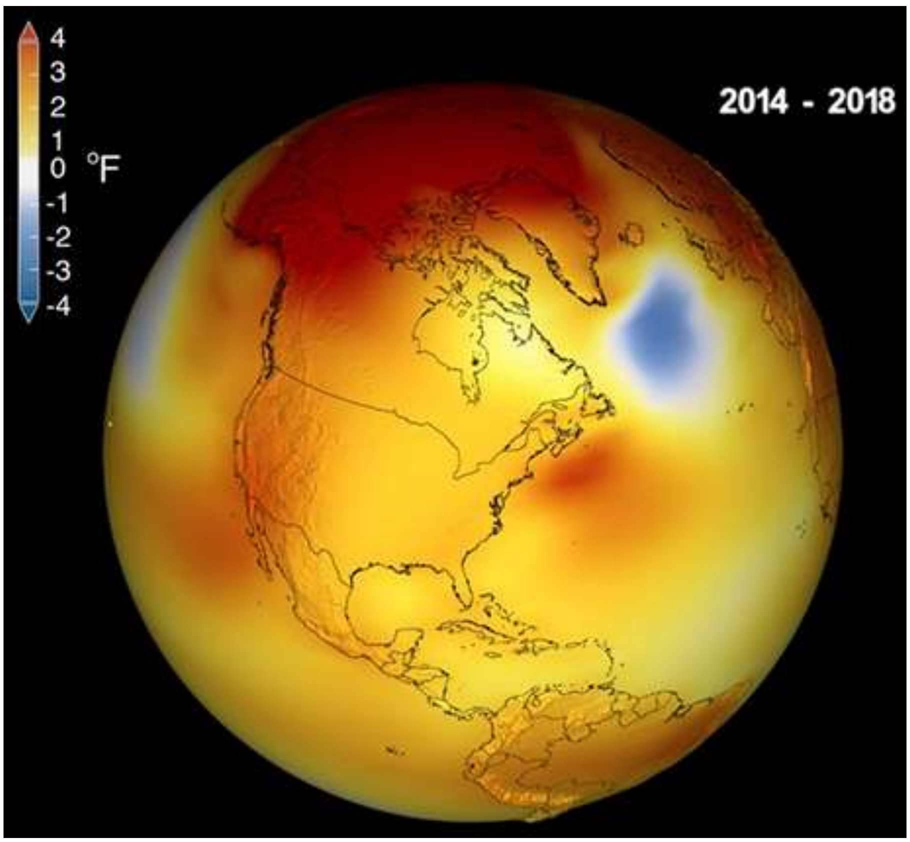
E. Conclusion and overview of linkages to next lesson and unit goals

In this lesson the students learned about the El Niño Southern Oscillation (ENSO) and how each phase of ENSO can change climate patterns around the world. Specifically, the students explored sea surface temperature anomaly & precipitation anomaly data in Panoply and evaluated an ENSO simulation from Prentice Hall to investigate how and why El Niño and La Niña conditions develop. Near the end of the lesson, the students extended their learning by making connections to wildfires, which is the theme of the unit's anchor phenomenon. Students used their knowledge of ENSO and the impacts on climate to explain the factors that led to the 2016 wildfires in the Amazon. In the next lesson the students will investigate changes in climate in the Arctic through Arctic Amplification and will make more connections to wildfires.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Changes in Climate & Wildfires
Lesson #3 Title: Arctic Amplification
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



X. Lesson #3: Arctic Amplification

A. Summary and Goals of Lesson

The goal of this lesson is to teach the students that regions of the world are impacted differently by climate change. Specifically, temperature in the Arctic region is increasing at a greater rate when compared to other locations due to Arctic Amplification. This **5E**-structured lesson is based on the following investigative phenomenon:

The Arctic regions have been warming at a greater rate than other regions around the world.

The lesson begins with the **Engage** activity in which students begin by analyzing the average global temperature trends from 1880 to 2019. The students will identify potential impacts of climate change and then predict the regions of the world they believe are increasing the most and least in temperature. The students will then discuss their predictions during a small group discussion. The goal of this activity is to elicit student prior knowledge and uncover any misconceptions.

During the **Explore** activity, the students will use NASA's GISTEMP surface temperature anomaly data to create maps to show the global anomalies in 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2019. The students will then use the maps to identify regions that experienced the greatest increase in temperature and will provide their own explanation about their observations.

During the **Explain** activity, the students will learn about Arctic Amplification and the role of surface albedo in the warming of the Arctic. The students will read an article from the NASA Earth Observatory titled Arctic Amplification, watch a NASA video titled This World in Black and White, and analyze average monthly albedo data in Panoply. The goal is for the students to establish a relationship between changes in surface albedo and surface temperature in the Arctic region.

During the **Elaborate** activity, the students will make connections between Arctic Amplification and wildfires in the Arctic. The students will use numerous NASA resources including videos and texts about wildfires in the Arctic to explain the climate factors involved in starting and spreading the wildfires.

During the **Evaluate** activity, the students will answer five assessment questions based on Arctic Amplification.

B. Table of Contents for lesson

C. 5 E Lesson Model Template

5E Lesson Plan - Earth Science

Unit: Changes in Climate & Wildfires **Topic**: Arctic Amplification

Prior Learning:

The following Next Generation Science Standards (NGSS) Performance Expectations (PE), Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEP), and Cross-Cutting Concepts (CCC) should have been experienced by the students in Middle School:

- **PE**: MS-ESS2-6
    - **DCI**: ESS2.D - Weather and Climate
    - **SEP**: Developing and Using Models
    - **CCC**: Systems & System Models

In this lesson, the students will analyze surface temperature anomaly data from NASA's GISTEMP to demonstrate how temperatures are changing at different rates across the world. If more background information is needed on the unequal rate of warming, go to this link to access a Global Climate Change NASA resource. In this lesson they will evaluate the regions that have experienced the greatest increase in temperature between 1950 and 2019. The students will then learn about Arctic amplification and how the snow and ice in the Arctic, or lack thereof, have led to greater temperature increases when compared to other locations around the world. The lesson is based on the following **investigative phenomenon:**

The Arctic regions have been warming at a greater rate than other regions around the world.

Students will build on their knowledge of prior learning in Middle School by investigating surface albedo and how changes in albedo can impact the amount of energy absorption. The ocean is able to absorb more sunlight than snow- and ice-covered surfaces, leading to greater increases in temperature. Changes in surface properties are due to the melting of snow and ice that results from increases in temperature, particularly in the Arctic. Students should know that lighter surfaces reflect more sunlight while darker surfaces absorb more sunlight. Students should also be able to make connections between the absorption of energy and changes in temperature. Prior to this lesson, the students should also have knowledge of the greenhouse effect and how greenhouse gases have been a large factor in the increasing temperatures Earth has been experiencing since the late 1800s. If students need a review of these concepts, go to this link to access a resource about global warming from the NASA Earth Observatory. Additionally, students should have knowledge of the environmental conditions favorable to the spread of wildfires from the introduction to the anchor phenomenon lesson.

Aim: Why aren't temperatures increasing the same amount in different regions of the world?

Next Generation Science Standards (NGSS):

Performance Expectation:

- **HS-ESS2-2**. – Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to Earth's systems.
    - **Science and Engineering Practices:**
        - Analyzing and Interpreting Data

- **Disciplinary Core Ideas**:
  - ESS2.A: Earth Materials and Systems
  - ESS2.D: Weather and Climate
- **Cross-cutting Concepts:**
  - Stability and Change

Performance Expectation:

- **HS-ESS2-4.** – Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate
  - **Science and Engineering Practices:**
    - Analyzing and Interpreting Data
  - **Disciplinary Core Ideas**:
    - ESS2.D: Weather and Climate
  - **Cross-cutting Concepts:**
    - Cause and Effect

Multiple Science Domains:
This lesson contains links between the Earth and Space Science DCIs listed above and the following Physical Science DCIs:

- PS3.B Conversion of Energy and Energy Transfer
- PS4.B Electromagnetic Radiation

Common Core Learning Standards (CCLS):

- **11-12.RST.3** - Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

- **11-12.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

- **11-12.RST.9** - Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Performance Objective: Students will be able to identify the regions of the world that have been experiencing the greatest increase in temperature by creating and analyzing surface temperature anomaly maps from 1950 to 2019 from NASA's GISTEMP.

Students will be able to investigate and explain the causes for Arctic amplification by watching a NASA video titled This World is Black and White and analyzing global average monthly albedo data in Panoply.

Materials:

- Class set of computers
- NASA Panoply software

Links to electronic resources are provided below:

- Link to NASA/NOAA temperature anomaly map
- Link to NASA GISS Surface Temperature Analysis map maker.
- Link to NASA Earth Observatory Article titled Arctic Amplification
- Link to NASA video titled This World is Black and White
- Link to NASA average monthly albedo data download
- Link to video titled NASA Studies How Arctic Fires Change the World
- Link to NASA article titled NASA Studies How Arctic Wildfires Change the World
- Link to NASA article titled NASA's Aqua Satellite Shows Siberian Fires Filling Skies With Smoke
- Link to NASA resource titled The Study of Earth as an Integrated System
- Link to NASA Research Feature titled Another Intense Summer of Wildfires in Siberia

Vocabulary:

- Anomaly
- Arctic amplification
- Positive feedback
- Albedo

Development of the 5E Lesson: Approximate Three-Day Lesson (Three 50-minute periods).

What the teacher does	What the student does	Time
1. ENGAGE Introduce the students to the ENGAGE activity. • As the students complete Q1, make sure the students are analyzing the overall trend from beginning to end. Circulate the room as the students answer Q2 – Q5. • Q4 & Q5 are meant to elicit prior knowledge and student thinking. It is alright if students are incorrect, as long as they are explaining their thinking. As the students are engaging in the Turn & Discuss activity with their group members, circulate to ensure all students are following the Turn & Discuss Quality Criteria. • Circulate during the discussions and look for common locations for both the greatest and least increase in temperature.	The students begin the ENGAGE activity by first analyzing the overall trend in changes in surface temperature from 1880 to 2019. The students describe potential impacts due to increasing temperatures. The students predict locations that are experiencing the greatest and least changes in temperature. The students engage in a small group Turn & Discuss based on their predicted locations of greatest and least changes in temperature. Each group needs to decide on one location for greatest and least increase in temperature. One member from each group will share their group's ideas with the class.	**25 min**

What the teacher does	What the student does	Time
After the small group discussions, have one representative from each group share their group's ideas with the class. ***Assessment Opportunity #1 (Student discussions about locations that are experiencing the greatest and least increases in temperature).***		
2. EXPLORE Show the students how to navigate to the GISS Surface Temperature Analysis map maker resource. Circulate the room as the students complete the EXPLORE activity. • Make sure the students are only creating maps for the years 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2019. • As the students are making the maps for a specific year, make sure they are using that year as both the **Time Interval Begin** and **End**. • Answers to Q4 and Q5 are meant to elicit student thinking. It is alright if these questions are answered incorrectly if the students have strong explanations to support their ideas. ***Assessment Opportunity #2 (Student answers to the Explore questions)***	The students access the GISS Surface Temperature Analysis map maker resource and learn how to create an annual surface temperature anomaly map. The students create surface temperature anomaly maps for the years 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2019. The students analyze the trends shown in the maps to identify regions that have had the greatest increase in temperature overtime. The students make predictions about why those locations experienced the greatest increase in temperature.	**25 min**
3. EXPLAIN Introduce the students to the NASA Earth Observatory article titled Arctic Amplification. • Have students read questions Q1 to Q4 before reading the article. • Check in with students about their answer to Q4. As the students access the NASA video titled This World is Black and White, ensure the students understand how black and white surfaces interact with sunlight through absorption and reflection, respectively.	The students read the NASA Earth Observatory article titled Arctic Amplification and answer Q1 to Q4 based on the article. The students watch the NASA video titled This World is Black and White to learn about albedo and its impact on surface temperature. The students will also be introduced to feedback loops in the Earth system. The students download average monthly albedo data and analyze the data in Panoply. Specifically, the students	**50 min**

What the teacher does	What the student does	Time
• Check in with the students about their answers to Q7 and Q8 before allowing them to move on to the next part of the EXPLAIN activity. ***Assessment Opportunity #3 (Student answers to the Explain questions, specifically Q4, Q7, Q8, and Q16)***	identify the locations with the greatest albedo and explain how increasing temperatures can change the surface albedo, further leading to changes in surface temperature.	
4. ELABORATE Circulate as the students complete the ELABORATE activity. • Ensure the students are viewing all resources before answering the questions! Each resource will provide information necessary for strong answers. Have students with model answers to Q2 and Q3 share their answers aloud with the class. Allow students the opportunity to make changes to their own answers. ***Assessment Opportunity #4 (Student answers to Q1 – Q3 of the Elaborate activity).***	The students answer Q1 based on the knowledge gained from the lesson thus far. The students read the questions for Q2 and Q3 and then review the five resources needed to effectively answer the questions. Students with model answers to Q2 and Q3 will share their answers aloud with the class. • Students can make changes to their own answers to Q2 and Q3.	**35 min**
5. EVALUATE Circulate as the students answer the EVALUATE questions. • Q3 – Q5 are questions adapted from previous New York State Earth Science Regents exams. ***Assessment Opportunity #5 (Student answers to the EVALUATE questions).***	The students answer the EVALUATE questions.	**15 min**

Summary/Conclusion: The students answer the EVALUATE questions.

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).

- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them. Students will also have access to highlighters during reading activities.

- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.

- Students are given time to answer questions during think pair share/group activities.

- Students are given sentence starters to use during class discussions.

- All images and graphs have alternative text.

- Students who need extra support can join the teacher for small group instruction and more efficient feedback.

- Students who are performing at a higher level can complete the tasks provided in the For Further Exploration part of the lesson plan.

- Students with a visual impairment can receive additional guidance from a sighted teacher about the color schemes in the surface temperature anomaly and albedo maps. Additionally, students have the freedom to choose a color scale in Panoply to suit their visual needs when evaluating global albedo.

- The closed-captioning feature on videos can be utilized to enhance the viewing experience for students.

Next Lesson: The next lesson the students will learn about atmospheric teleconnections, specifically ENSO and the Arctic Oscillation (AO).

For Further Exploration:

1. Go to this link to learn about NASA missions and satellites used to gather information about wildfires.

2. Go to this link to access NASA resource FIRMS (Fire Information for Resource Management Systems) to view the locations of wildfires within the last 24 hours.

Notes For Revision:

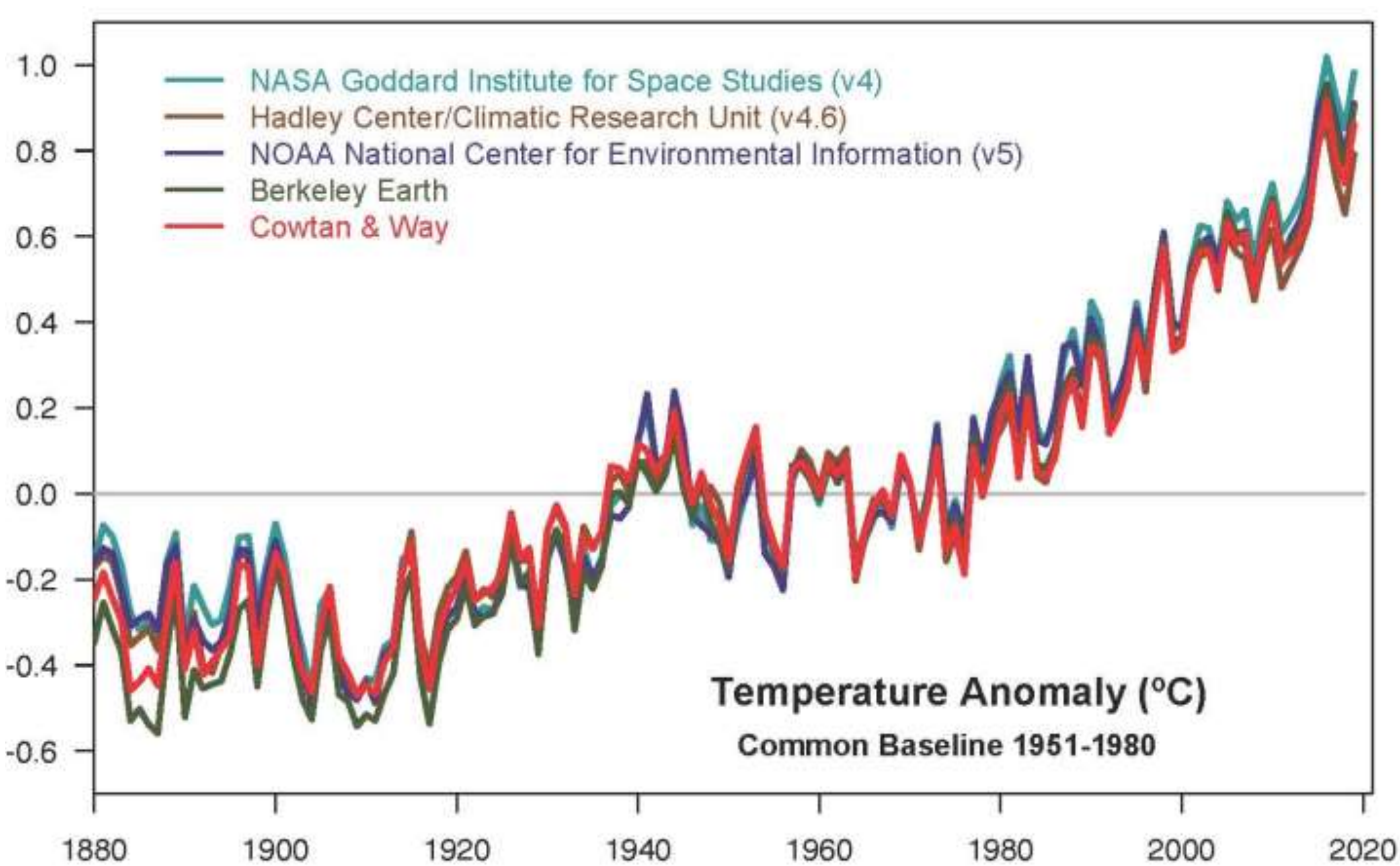
D. Supporting Documents (order according to sequence of lesson)

Modern-Day Climate Change & Wildfires Activity

Investigative Phenomenon – *The Arctic regions have been warming at a greater rate than other regions around the world.*

ENGAGE

Step 1. The graph below from NASA/NOAA shows the change in the average global temperature anomaly from 1880 to 2019. Data is provided from five different data sources. The graph can be accessed at this link.



Q1. All data sources show a similar trend in the average temperature anomaly data. Describe the overall trend in the average temperature anomaly data from 1880 to 2019.

____

____

Q2. Throughout Earth's history, climate has changed many times. Climate change can be due to an average increase or decrease in global temperatures.

Circle one of the following below. The climate change we are experiencing in modern times is due to:

An increase in average global temperature ***A decrease in average global temperature***

Q3. As average global temperatures on Earth continue to rise, how will Earth be impacted? Please describe four possible impacts.

(1) ____

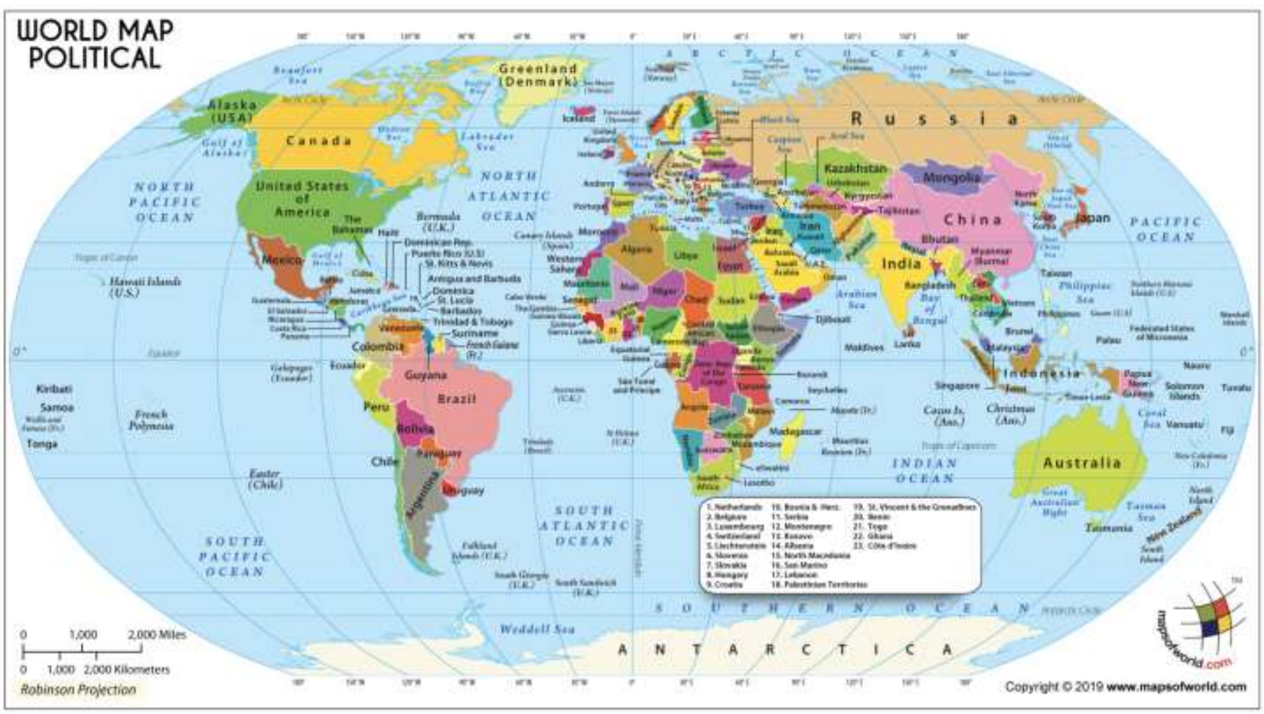
(2) ____

(3) ____

(4) ____

Q4. Using the world map below, identify two locations you believe will experience the **greatest increases** in temperature due to climate change. Explain your reasoning for choosing each location.

Note: *Locations can be general or specific. What is more important is your reasoning for choosing each location.*



Location #1: ____

Explanation: ____

____

Location #2: ____

Explanation: ____

____

Q5. Using the world map above, identify two locations you believe will experience the **smallest increases** in temperature due to climate change. Explain your reasoning for choosing each location.

Note: *Locations can be general or specific. What is more important is your reasoning for choosing each location.*

Location #1: ____

Explanation: ____

____

Location #2: ____

Explanation: ____

____

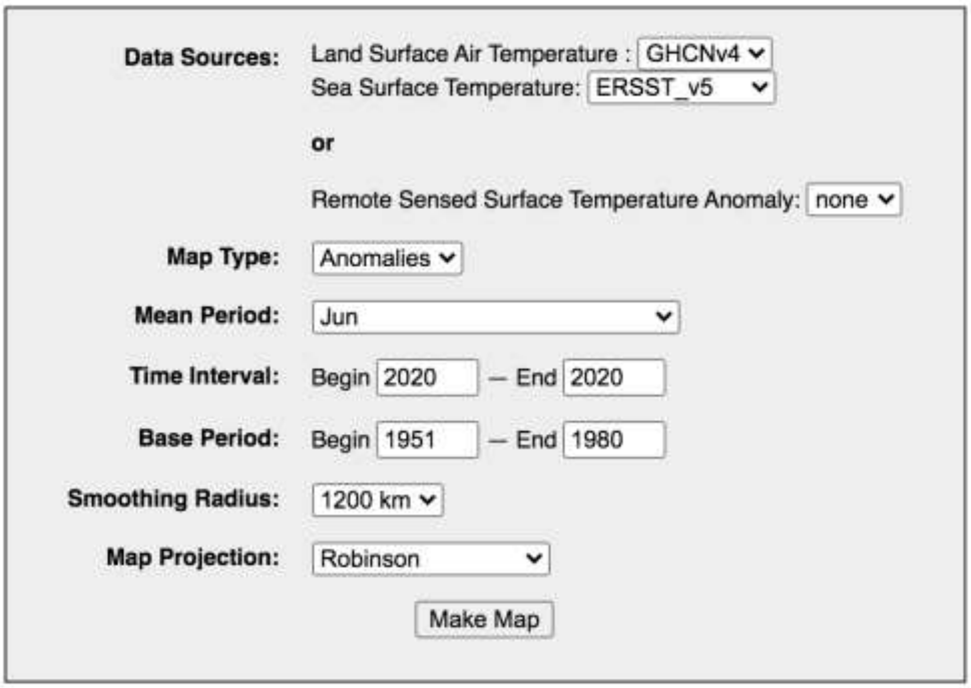
Step 2. With a small group, engage in a 5-minute Turn & Discuss based on your answers to Q4 and Q5. By the end of five minutes, your group should come to a consensus for one location that will experience the greatest increase, and another location that will experience the greatest decrease. Select one student to represent the ideas of the group with the class after the small group discussion. Be prepared to explain why your group chose each location.

Use the Turn & Discuss Quality Criteria to guide your discussion!

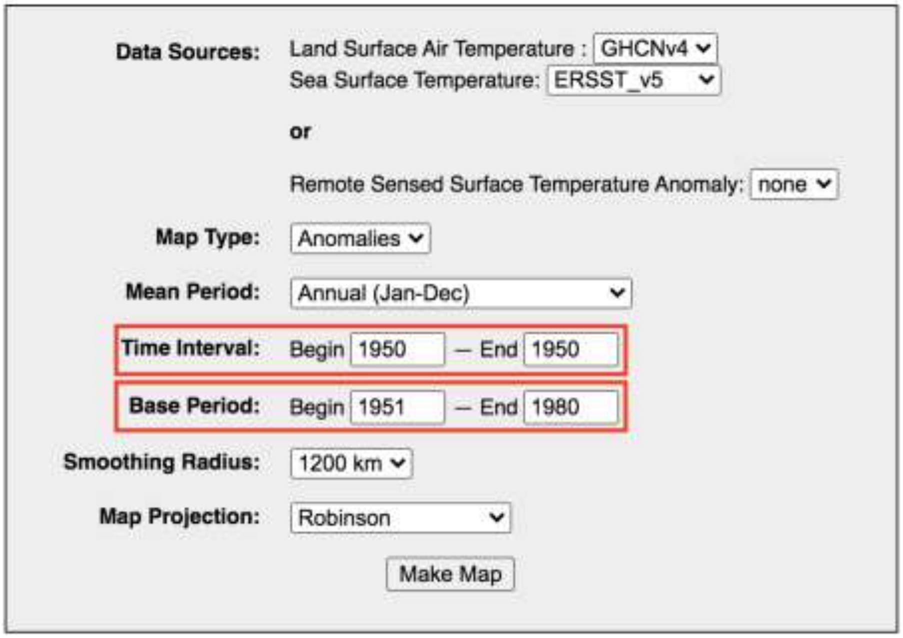
EXPLORE

Step 1. [Go to this link to access GISS Surface Temperature Analysis (v4)](), which allows users to create global surface temperature anomaly maps.

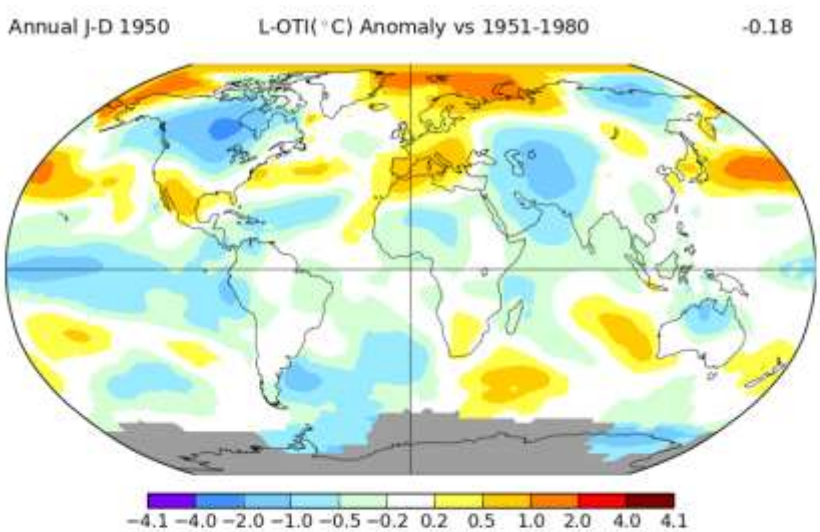
Step 2. We want to explore the changes in global temperature anomalies from 1950 to 2019. To do this, we want to create maps that show the annual average temperature anomaly. You should see a gray box on the webpage, as shown in the image below, which allows users to specify the variables to use to create the maps.



Step 3. Change the **Mean Period** to **Annual (Jan – Dec)**, change the **Time Interval** to **Begin: 1950** and **End: 1950**, and then click **Make Map**, as shown in the image below.



Step 4. You should now see a map below the gray box as shown in the image below:



The map shows the global average temperature anomalies for the year 1950.

Step 5. Copy and paste the map into the data table below under the year 1950. Alter the size of the image so the image fits within the data table.

Q1. For each year listed in the data table, use the GISS Surface Temperature Analysis (v4) map maker to create the global average temperature anomaly maps for 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2019. Copy and paste each map into the data table below.

**Note: Make sure the Begin and End times are the same as the year of interest.*

1950 Annual Average	1960 Annual Average

1970 Annual Average	1980 Annual Average

1990 Annual Average	2000 Annual Average

2010 Annual Average	2019 Annual Average

Q2. In general, describe how the average global temperature anomalies have changed overtime from 1950 to 2019.

____

____

Q3. Describe the locations that experienced the greatest increase in temperature anomalies from 1950 to 2019.

____

____

Q4. Based on your answer to Q3, are you surprised by the locations that experienced the greatest increase in temperature anomalies from 1950 to 2019? Why or why not?

____

____

Q5. Why do you think the locations you described in Q3 experienced the greatest increase in temperature anomalies from 1950 to 2019?

____

____

EXPLAIN

Step 1. The high latitudes of Earth's Arctic regions have been increasing in temperature more than locations in the middle to low latitudes. Go to this link to read an article from the NASA Earth Observatory titled Arctic Amplification.

As you read the article, answer Q1 to Q4 below.

Q1. The article states that "Since the mid-20th Century, average global temperatures have warmed about 0.6°C (1.1°F), but the warming has not occurred equally everywhere." How does the warming in the Arctic compare to the warming in the mid-latitudes?

____

____

Q2. Why are the Arctic regions warming faster than other regions?

____

____

Q3. How do thunderstorms in the tropics lead to more warming in the Arctic regions?

____

____

Q4. Based on the information described in the text, describe the term "Arctic amplification".

____

____

Step 2. Go to this link to view the NASA video titled This World is Black and White. Read Q5 to Q8 before watching the video, and then use the video to answer each question.

Q5. Why does the increase in **black** daisies lead to an increase in temperature?

____

____

Q6. Why does the increase in **white** daisies lead to a decrease in temperature?

____

____

Q7. What is albedo, and what does it mean for an object to have a high albedo?

____

____

Q8. Explain how Arctic amplification is an example positive feedback.

____

____

____

Step 3. Albedo is a measure of the reflectivity of a surface. A surface with a high albedo will reflect more sunlight (absorb less), while a surface with a low albedo will absorb more sunlight (reflect less). Clouds and snow-covered surfaces have higher albedos, while water surfaces and darker surfaces have lower albedos.

Go to this link to access albedo data from NASA. Then, look for the section titled **Other Available File Formats** and click on the link titled **netCDF** as shown in the image below. This will download global average monthly albedo data. The dataset contains 12 time slices, one for each month.

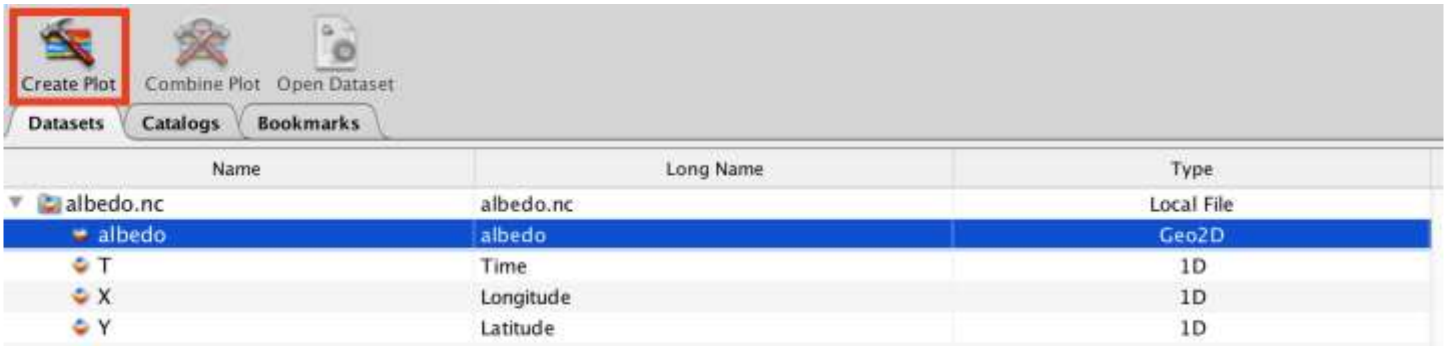
Other Available File Formats

Full Information Formats These files contain all of the available metadata.	
OPeNDAP	A system which downloads data directly to software, such as matlab, Ferret, GrADS, etc. Specific instructions are available in the table above. Note: OPeNDAP was formerly known as DODS (Distributed Oceanographic Data System). More information
netCDF (network Common Data Form)	A commonly supported self-describing data format. More information

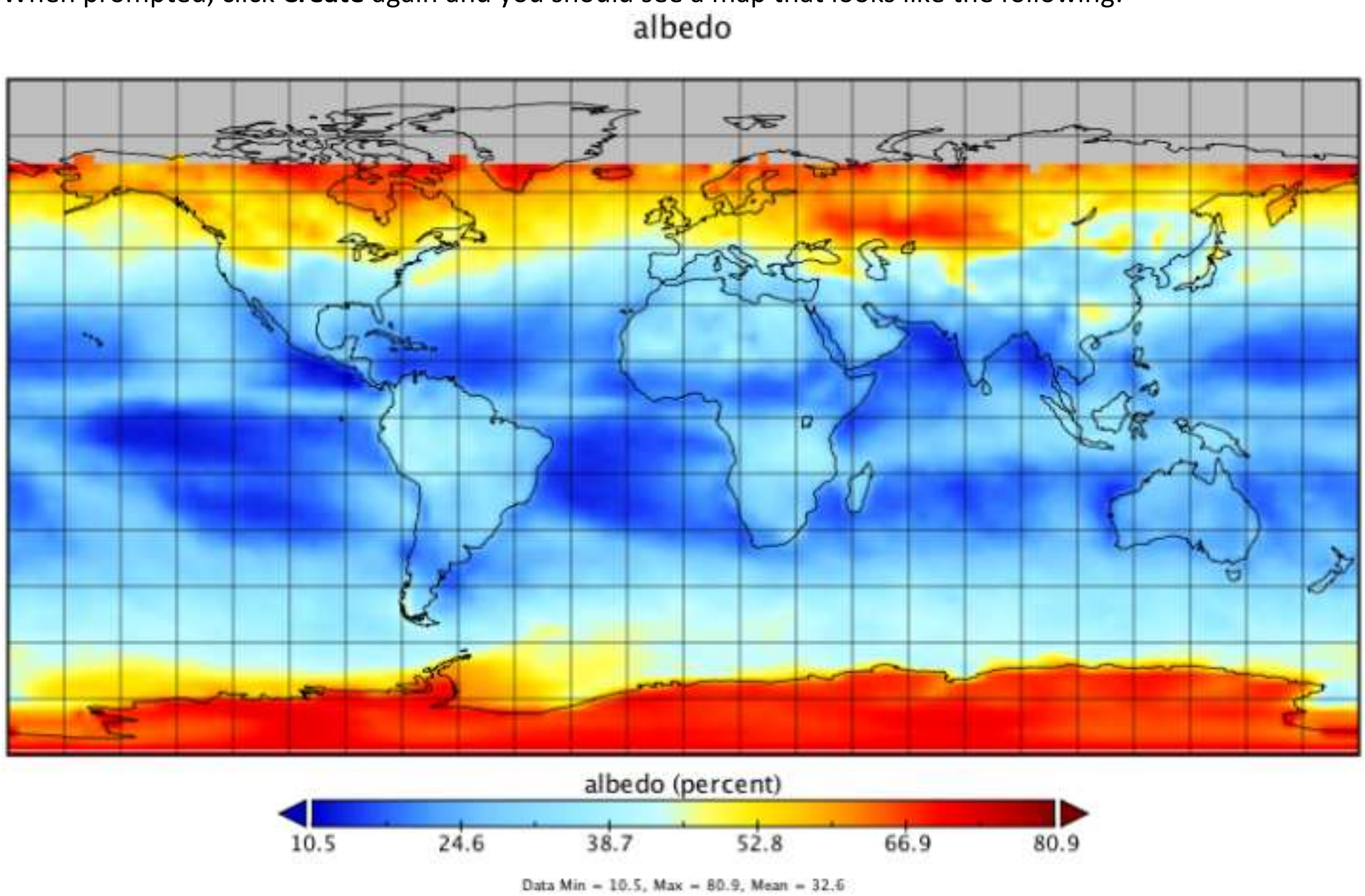
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **data.nc.** Change the name of the file to **albedo.nc** by right-clicking on the dataset and selecting "rename".

Step 4. Open the **albedo.nc** dataset in Panoply.

Step 5. In Panoply, go to the **albedo.nc** dataset and click on the variable titled **"albedo"** and then click **"Create Plot"** in the top left corner as shown below:



When prompted, click **Create** again and you should see a map that looks like the following:



Step 6. The map currently displayed is the average albedo during the month of January. This can be verified by clicking on the **Array(s)** tab near the bottom of Panoply, as shown in the image below.

Step 7. Albedo is measured as a percentage. The scale below the map shows an albedo range of 10.5% to 80.9%. Blue colors represent a lower albedo, while red colors represent a higher albedo.

Q9. What does it mean for a surface to have a high albedo?

____

____

Q10. What does it mean for a surface to have a low albedo?

____

____

Step 8. Go to the **Array(s)** tab near the bottom of Panoply and change the **Time** to **3** to represent average albedo during the month of **March**. During March, the sea ice extent (area) in the Northern Hemisphere higher latitudes is greatest.

Q11. Describe the locations with a relatively high albedo.

____

____

Q12. Why do these locations have a relatively high albedo?

____

____

Q13. How does the high albedo of the locations described in Q11 influence the amount of sunlight reflected?

____

____

Q14. Explain how a surface with a high albedo would impact temperature.

____

____

Q15. As average temperature on Earth continues to rise, how do you expect albedo in the Arctic regions to change? Then, explain why this change will occur.

Change in Arctic albedo: ____

Explanation: ____

____

Q16. Based on what you learned from Q1 to Q15, explain why Arctic amplification is occurring, resulting in a greater increase in temperature in the Arctic compared to the mid to low latitudes. Use the term *albedo* in your answer.

____

____

____

____

ELABORATE

Q1. There has been an increase in the number of wildfires in the Arctic due to changes in surface temperature anomalies. Explain why the Arctic has been experiencing larger and more severe wildfires. Your answer should include information about surface temperature anomalies, albedo, Arctic amplification, and the environmental conditions favorable to wildfires.

____

____

____

____

Step 1. Below are five NASA resources related to wildfires in the Arctic.

- Link to video titled NASA Studies How Arctic Fires Change the World
- Link to NASA article titled NASA Studies How Arctic Wildfires Change the World
- Link to NASA article titled NASA's Aqua Satellite Shows Siberian Fires Filling Skies With Smoke
- Link to NASA resource titled The Study of Earth as an Integrated System that explains positive and negative feedback.
- Link to NASA Research Feature titled Another Intense Summer of Wildfires in Siberia

Utilize each resource to answer the questions below.

Q2. Why are wildfires in the Arctic an example of positive feedback?

____

____

____

____

Q3. Explain why wildfires in the Arctic can lead to changes in global climate.

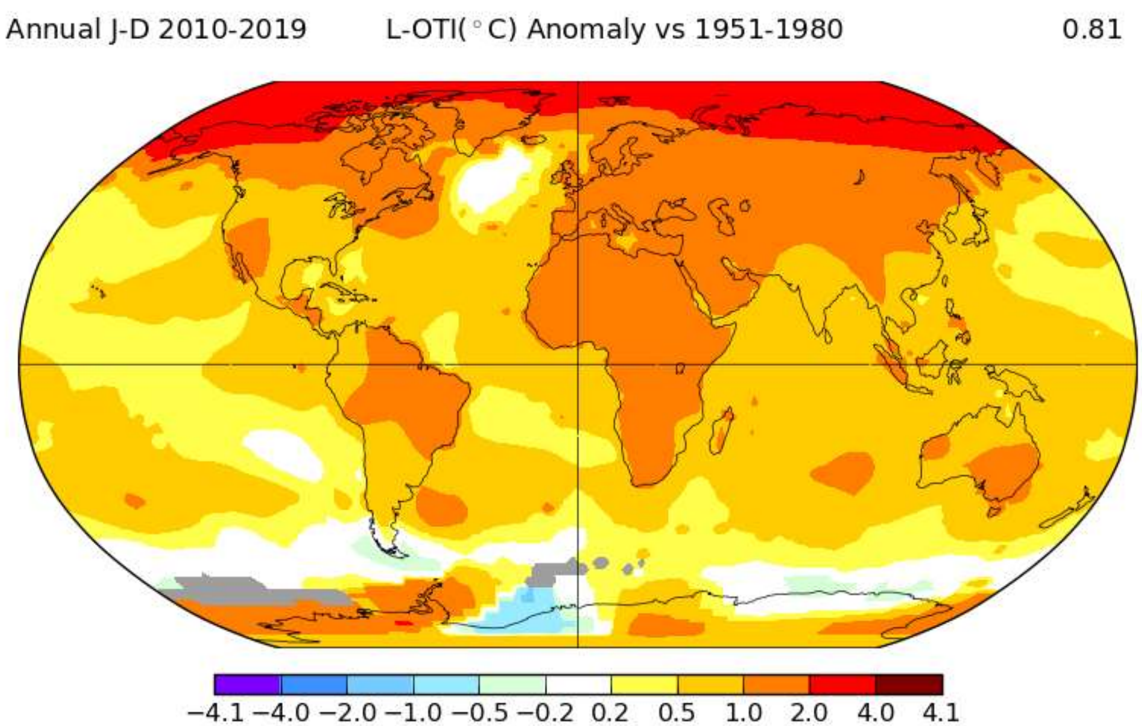
____

____

____

EVALUATE – Q3 – Q5 are adapted from the New York State Earth Science Regents.

Use the map below to answer Q1 and Q2. The map shows average global surface temperature anomalies from 2010 – 2019 from GISTEMP.



Q1. Which regions of the world have experienced a greater increase in temperature due to climate change?

____

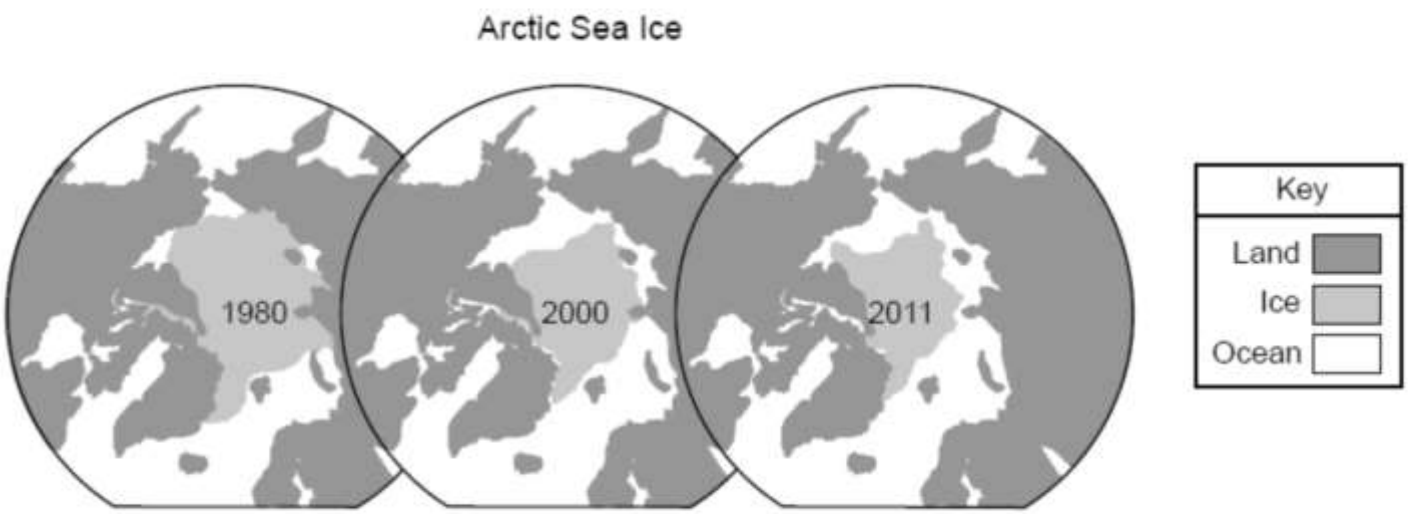
____

Q2. Why are these regions experiencing a greater increase in temperature when compared to the rest of the world?

____

____

Use the maps below to answer Q3 and Q5. The north polar view maps show the average area covered by Arctic Sea ice in September of 1980, 2000, and 2011. Map is from the New York State Earth Science Regents.



Q3. How has the amount of ice in the Arctic Sea changed overtime?

____

____

Q4. How has this change in the amount of Arctic Sea ice influenced the albedo of the Arctic?

____

____

Q5. Explain how this change in Arctic Sea ice has led to Arctic amplification.

____

____

____

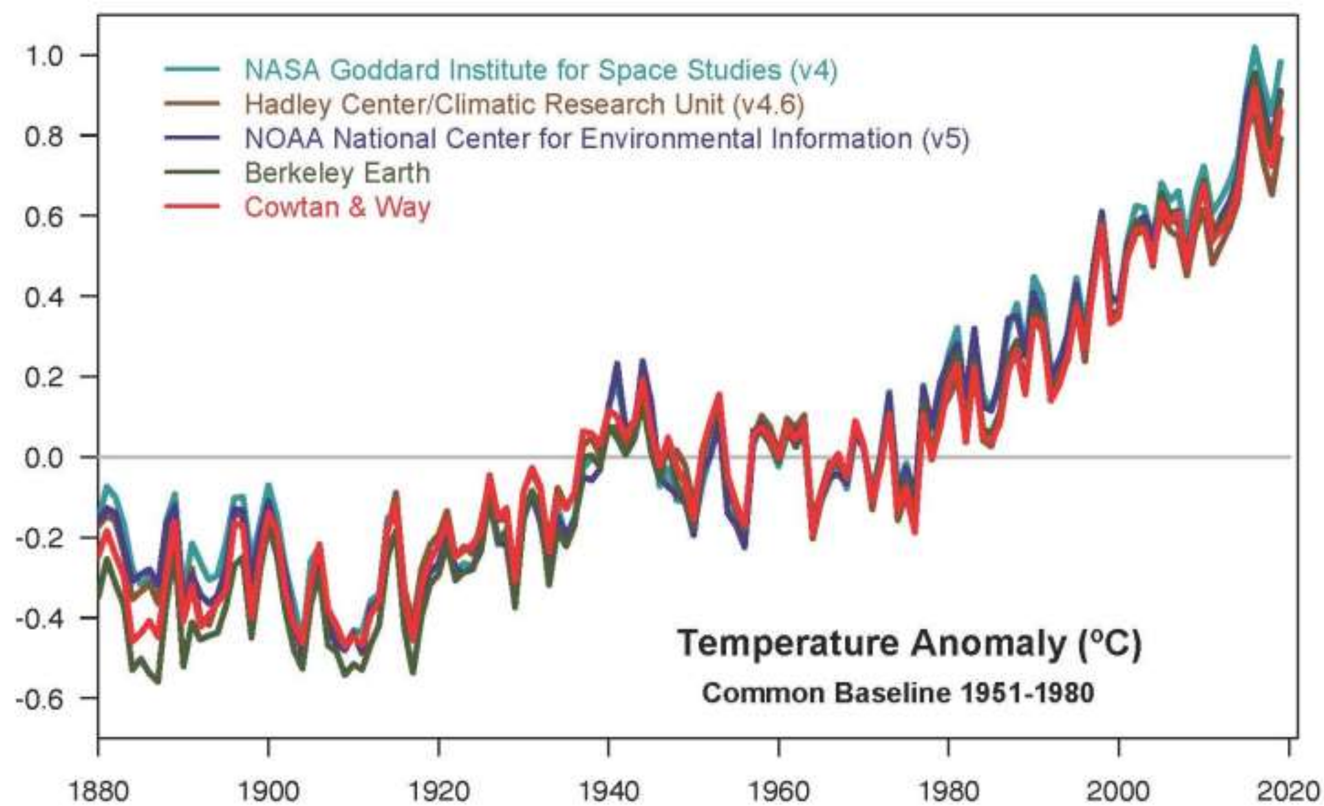
____

Answers - Modern-Day Climate Change & Wildfires Activity

Investigative Phenomenon – *The Arctic regions have been warming at a greater rate than other regions around the world.*

ENGAGE

Step 1. The graph below from NASA/NOAA shows the change in the average global temperature anomaly from 1880 to 2019. Data is provided from five different data sources. The graph can be accessed at this link.



Q1. All data sources show a similar trend in the average temperature anomaly data. Describe the overall trend in the average temperature anomaly data from 1880 to 2019.

From 1880 to 2019, the average temperature anomaly increased overall.

Q2. Throughout Earth's history, climate has changed many times. Climate change can be due to an average increase or decrease in global temperatures.

Circle one of the following below. The climate change we are experiencing in modern times is due to:

An increase in average global temperature ***A decrease in average global temperature***

Q3. As average global temperatures on Earth continue to rise, how will Earth be impacted? Please describe four possible impacts. **Answer can include, but are not limited to:**

(1) **Rising sea levels**

(2) **Loss of habitats**

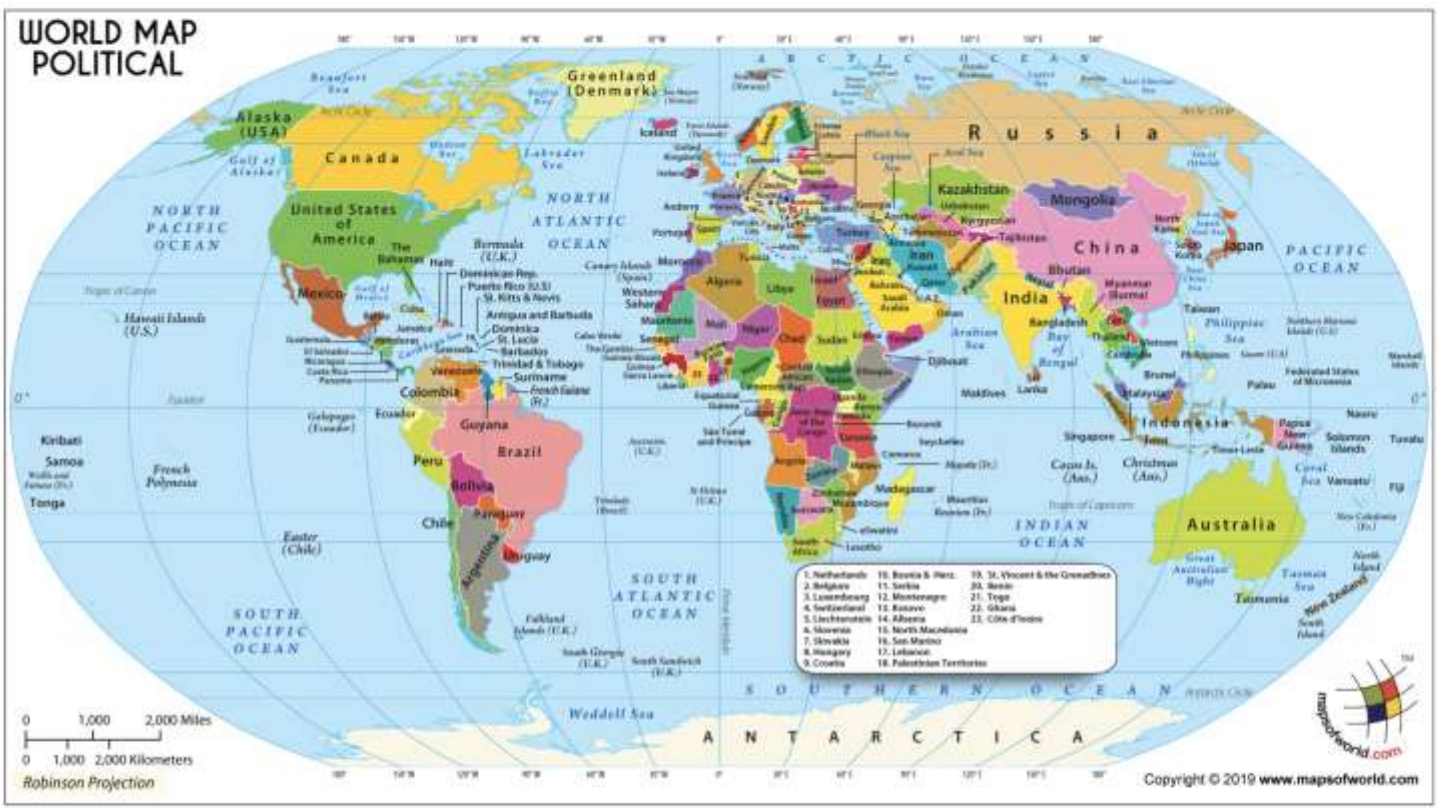
(3) **Increase in the number of droughts and heat waves**

(4) **Change in the food supply due to changes in the growing season**

More impacts can be found at this link to a NASA resource about climate change.

Q4. Using the world map below, identify two locations you believe will experience the **greatest increases** in temperature due to climate change. Explain your reasoning for choosing each location.

Note: *Locations can be general or specific. What is more important is your reasoning for choosing each location.*



Location #1: **Answers will vary based on student prior knowledge and experience.**

Explanation: **Make sure students give a thorough explanation for their prediction. It does not need to be correct, but it is important for the students to explain their thinking.**

Location #2: **Answers will vary based on student prior knowledge and experience.**

Explanation: **Make sure students give a thorough explanation for their prediction. It does not need to be correct, but it is important for the students to explain their thinking.**

Q5. Using the world map above, identify two locations you believe will experience the **smallest increases** in temperature due to climate change. Explain your reasoning for choosing each location.

Note: *Locations can be general or specific. What is more important is your reasoning for choosing each location.*

Location #1: **Answers will vary based on student prior knowledge and experience.**

Explanation: **Make sure students give a thorough explanation for their prediction. It does not need to be correct, but it is important for the students to explain their thinking.**

Location #2: **Answers will vary based on student prior knowledge and experience.**

Explanation: **Make sure students give a thorough explanation for their prediction. It does not need to be correct, but it is important for the students to explain their thinking.**

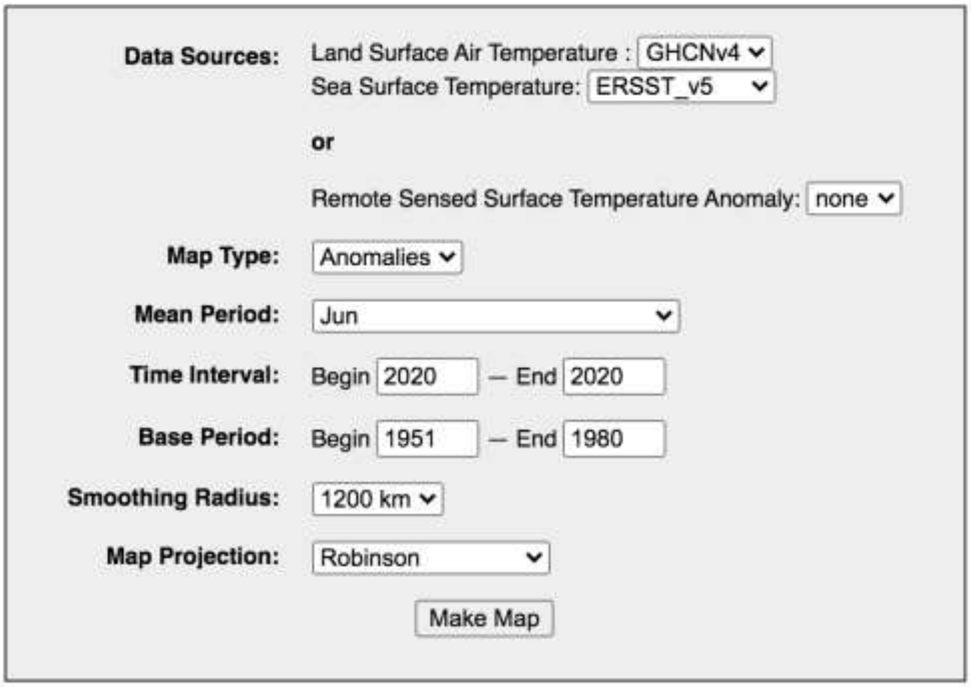
Step 2. With a small group, engage in a 5-minute Turn & Discuss based on your answers to Q4 and Q5. By the end of five minutes, your group should come to a consensus for one location that will experience the greatest increase, and another location that will experience the greatest decrease. Select one student to represent the ideas of the group with the class after the small group discussion. Be prepared to explain why your group chose each location.

Use the Turn & Discuss Quality Criteria to guide your discussion!

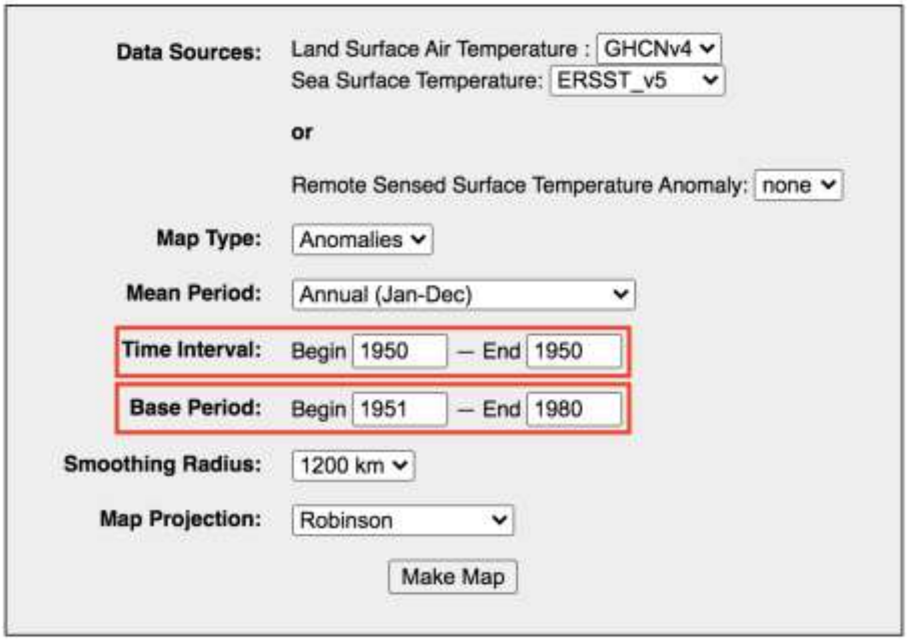
EXPLORE

Step 1. Go to this link to access GISS Surface Temperature Analysis (v4), which allows users to create global surface temperature anomaly maps.

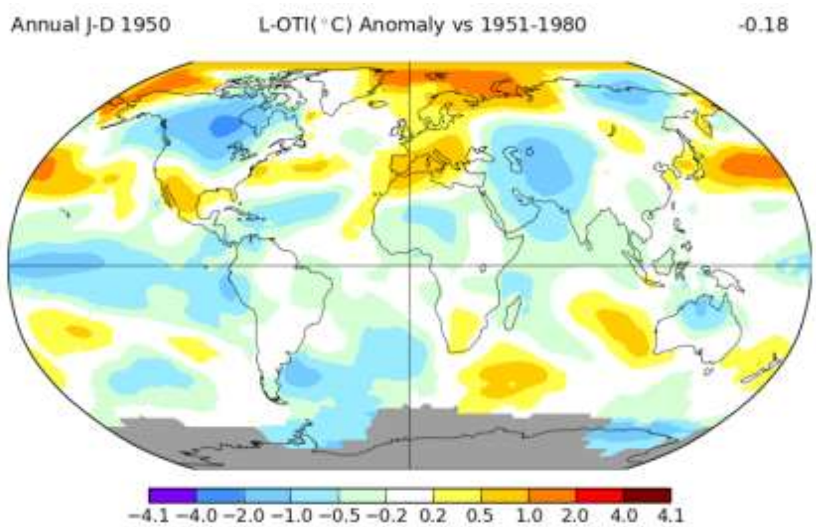
Step 2. We want to explore the changes in global temperature anomalies from 1950 to 2019. To do this, we want to create maps that show the annual average temperature anomaly. You should see a gray box on the webpage, as shown in the image below, which allows users to specify the variables to use to create the maps.



Step 3. Change the **Mean Period** to **Annual (Jan – Dec)**, change the **Time Interval** to **Begin: 1950** and **End: 1950**, and then click **Make Map**, as shown in the image below.



Step 4. You should now see a map below the gray box as shown in the image below:



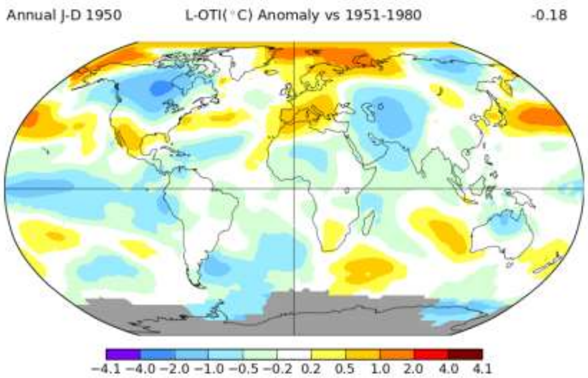
The map shows the global average temperature anomalies for the year 1950.

Step 5. Copy and paste the map into the data table below under the year 1950. Alter the size of the image so the image fits within the data table.

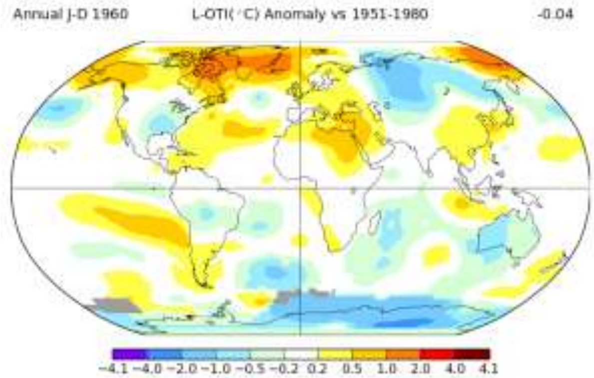
Q1. For each year listed in the data table, use the GISS Surface Temperature Analysis (v4) map maker to create the global average temperature anomaly maps for 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2019. Copy and paste each map into the data table below.

**Note*: *Make sure the Begin and End times are the same as the year of interest.*

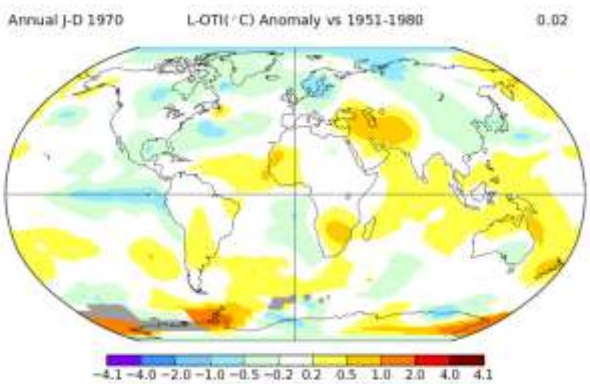
1950 Annual Average



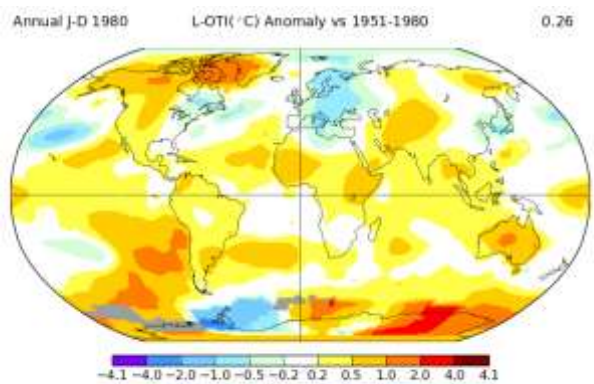
1960 Annual Average



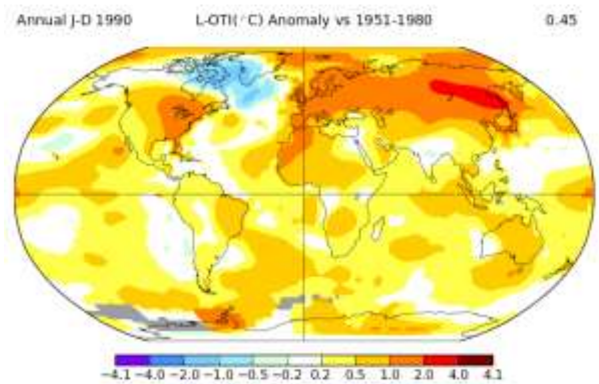
1970 Annual Average



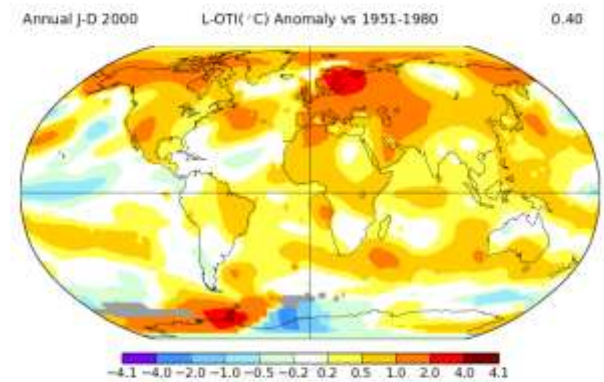
1980 Annual Average



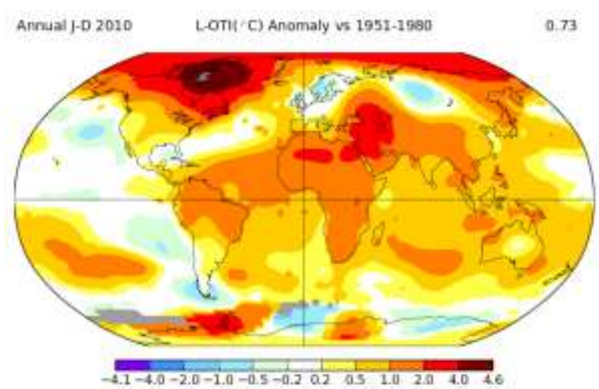
1990 Annual Average



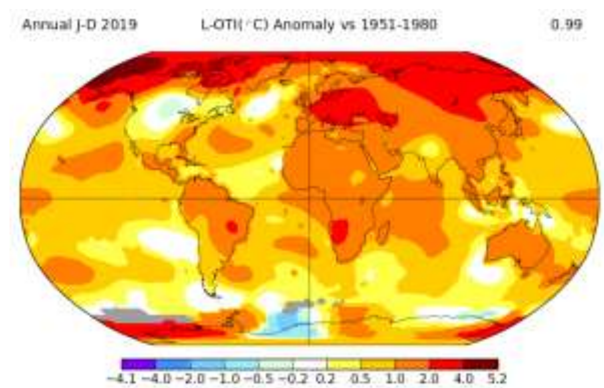
2000 Annual Average



2010 Annual Average



2019 Annual Average



Q2. In general, describe how the average global temperature anomalies have changed overtime from 1950 to 2019.

In general, average global temperature anomalies have increased from 1950 to 2019.

Q3. Describe the locations that experienced the greatest increase in temperature anomalies from 1950 to 2019.

Locations in the Arctic (extreme high latitudes of the Northern Hemisphere), specifically northern North America, Greenland, and northern Asia (Siberia), experienced the greatest increase in temperature anomalies.

Q4. Based on your answer to Q3, are you surprised by the locations that experienced the greatest increase in temperature anomalies from 1950 to 2019? Why or why not?

An anticipated student response for this question is it is surprising that the Arctic region is experiencing the greatest increase in temperature due to the snow and ice that covers much of these areas. Students may also refer to the lack of daylight hours during the Northern Hemisphere winter, leading to potentially cooler temperatures from the lack of sunlight.

Q5. Why do you think the locations you described in Q3 experienced the greatest increase in temperature anomalies from 1950 to 2019?

Answers will vary here, and it is more important that the students explain their thinking rather than arriving at the correct answer. Students are not expected to have a correct answer to this question at this stage of the lesson.

EXPLAIN

Step 1. The high latitudes of Earth's Arctic regions have been increasing in temperature more than locations in the middle to low latitudes. Go to this link to read an article from the NASA Earth Observatory titled Arctic Amplification.

As you read the article, answer Q1 to Q4 below.

Q1. The article states that "Since the mid-20th Century, average global temperatures have warmed about 0.6°C (1.1°F), but the warming has not occurred equally everywhere." How does the warming in the Arctic compare to the warming in the mid-latitudes?

Temperatures in the Arctic have increased twice as fast when compared to the mid-latitudes.

Q2. Why are the Arctic regions warming faster than other regions?

The Arctic is warming faster than other regions because of the loss of sea ice. As temperatures increase, the sea ice melts. Ice reflects sunlight and the reduction of ice leads to more absorption of solar energy. This increased absorption of sunlight will further increase temperatures.

Q3. How do thunderstorms in the tropics lead to more warming in the Arctic regions?

Thunderstorms have the ability to transport heat from the surface to the upper atmosphere. Upper level winds can then take the heat and transport it to higher latitudes, such as the Arctic region.

Q4. Based on the information described in the text, describe the term "Arctic amplification".

Arctic amplification occurs as the sea ice melts due to increasing temperatures. Melted sea ice does not reflect as much sunlight, leading to more absorption of sunlight. This further melts the ice more, leading to more absorption and even more warming.

Step 2. Go to this link to view the NASA video titled This World is Black and White. Read Q5 to Q8 before watching the video, and then use the video to answer each question.

Q5. Why does the increase in **black** daisies lead to an increase in temperature?

Black daises absorb more sunlight due to their dark color, which increases temperature.

Q6. Why does the increase in **white** daisies lead to a decrease in temperature?

White daises absorb more sunlight due to their light color, which decreases temperature.

Q7. What is albedo, and what does it mean for an object to have a high albedo?

Albedo is the amount of reflectance for a particular surface. A high albedo means the surface reflects a large amount of sunlight.

Q8. Explain how Arctic amplification is an example of positive feedback.

Arctic amplification is an example of positive feedback because the initial increase in temperature results in the melting of sea ice, which leads to a greater absorption of energy. This increased absorption further increases temperature. Since the initial increase in temperature is further increased, Arctic amplification is an example of positive feedback.

Step 3. Albedo is a measure of the reflectivity of a surface. A surface with a high albedo will reflect more sunlight (absorb less), while a surface with a low albedo will absorb more sunlight (reflect less). Clouds and snow-covered surfaces have higher albedos, while water surfaces and darker surfaces have lower albedos.

Go to this link to access albedo data from NASA. Then, look for the section titled **Other Available File Formats** and click on the link titled **netCDF** as shown in the image below. This will download global average monthly albedo data. The dataset contains 12 time slices, one for each month.

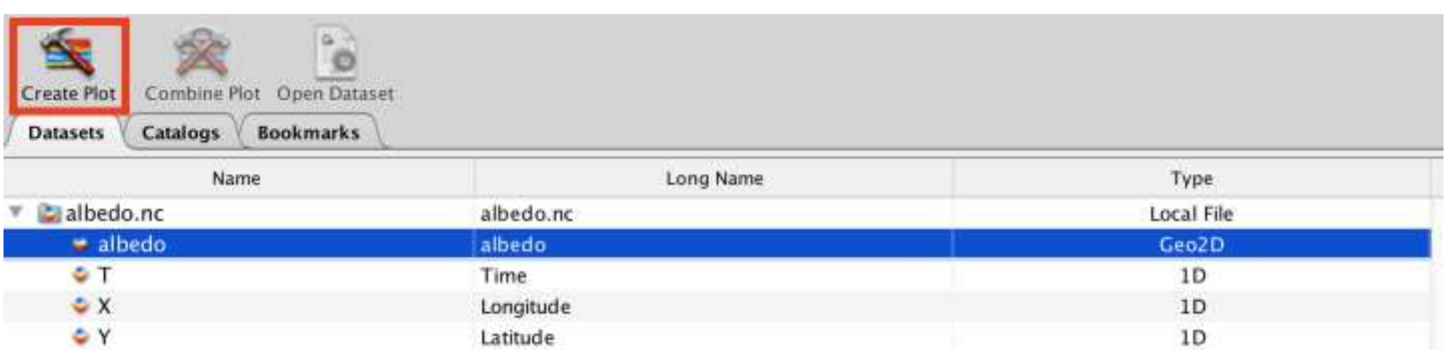
Other Available File Formats

Full Information Formats These files contain all of the available metadata.	
OPeNDAP	A system which downloads data directly to software, such as matlab, Ferret, GrADS, etc. Specific instructions are available in the table above. Note: OPeNDAP was formerly known as DODS (Distributed Oceanographic Data System). More information
netCDF (network Common Data Form)	A commonly supported self-describing data format. More information

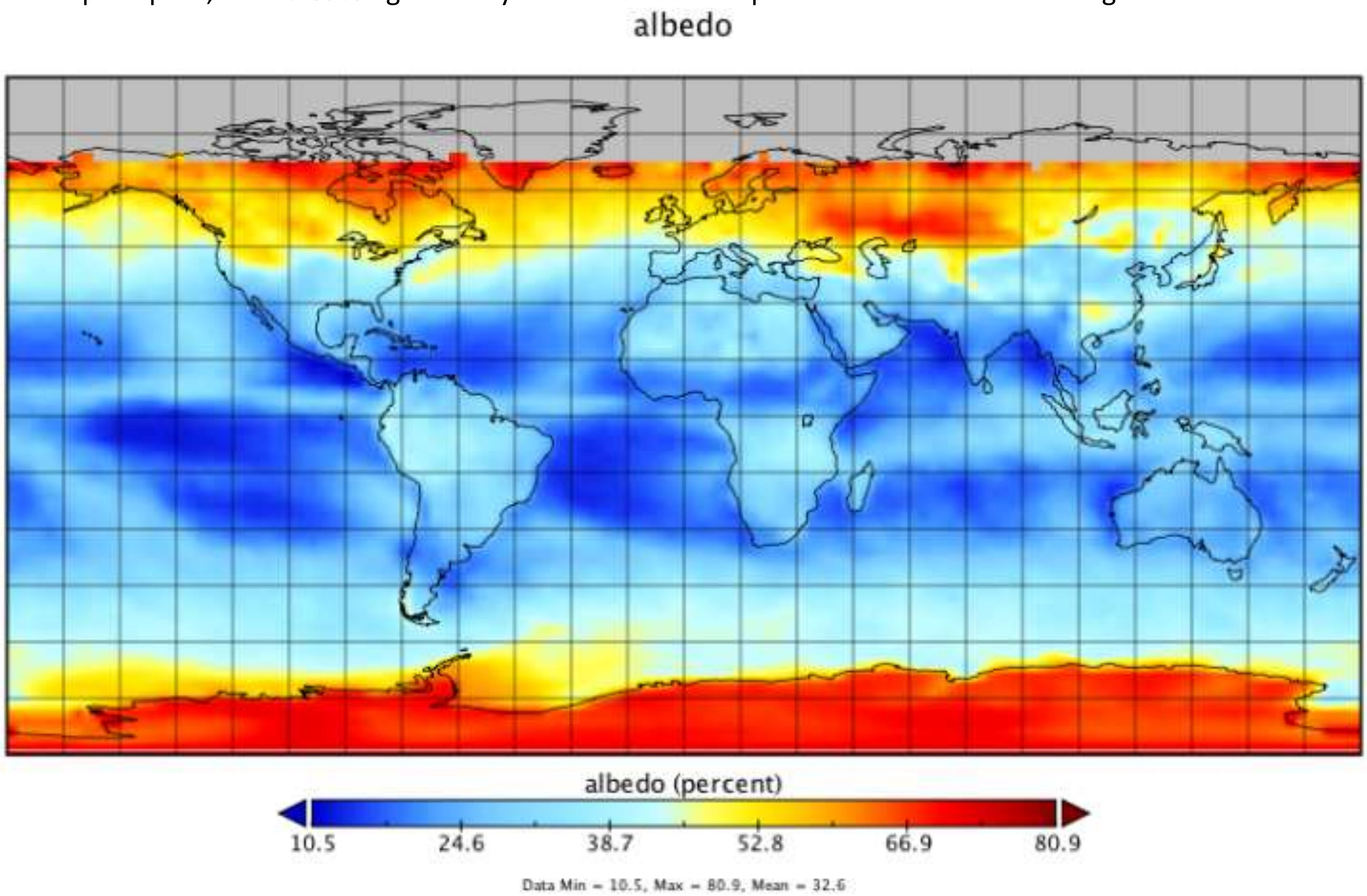
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **data.nc.** Change the name of the file to **albedo.nc** by right-clicking on the dataset and selecting “rename”.

Step 4. Open the **albedo.nc** dataset in Panoply.

Step 5. In Panoply, go to the **albedo.nc** dataset and click on the variable titled **“albedo”** and then click **“Create Plot”** in the top left corner as shown below:



When prompted, click **Create** again and you should see a map that looks like the following:



Step 6. The map currently displayed is the average albedo during the month of January. This can be verified by clicking on the **Array(s)** tab near the bottom of Panoply, as shown in the image below.

Step 7. Albedo is measured as a percentage. The scale below the map shows an albedo range of 10.5% to 80.9%. Blue colors represent a lower albedo, while red colors represent a higher albedo.

Q9. What does it mean for a surface to have a high albedo?

A surface with a high albedo means that the surface reflects a large amount of sunlight (absorbs less).

Q10. What does it mean for a surface to have a low albedo?

A surface with a low albedo means that the surface absorbs a large amount of sunlight (reflects less).

Step 8. Go to the **Array(s)** tab near the bottom of Panoply and change the **Time** to **3** to represent average albedo during the month of **March**. During March, the sea ice extent (area) in the Northern Hemisphere higher latitudes is greatest.

Q11. Describe the locations with a relatively high albedo.

The locations with a relatively high albedo are the higher latitudes of the Northern and Southern Hemispheres. Specifically, northern North America, Greenland, northern Asia, and Antarctica have the highest albedo values.

Q12. Why do these locations have a relatively high albedo?

These locations have a relatively high albedo because they are covered in snow and ice. Snow and ice surfaces have high albedos and reflect a large amount of sunlight.

Q13. How does the high albedo of the locations described in Q11 influence the amount of sunlight reflected?

The regions of northern North America, Greenland, northern Asia, and Antarctica reflect more sunlight due to their high albedo.

Q14. Explain how a surface with a high albedo would impact temperature.

Since a surface with a high albedo reflects more sunlight, there will be a decrease in temperature. (Surfaces that absorb sunlight experience higher temperatures.)

Q15. As average temperature on Earth continues to rise, how do you expect albedo in the Arctic regions to change? Then, explain why this change will occur.

Change in Arctic albedo: **Surface albedo in the Arctic regions will decrease.**

Explanation: **Albedo will decrease because the increasing temperatures will melt the sea ice. The loss of the snow and ice will reduce the albedo, allowing for a greater absorption of solar energy.**

Q16. Based on what you learned from Q1 to Q15, explain why Arctic amplification is occurring, resulting in a greater increase in temperature in the Arctic compared to the mid to low latitudes. Use the term *albedo* in your answer.

Arctic amplification is occurring because the increase in temperature is melting the snow and sea ice in the region. This reduces the albedo of the surface, allowing for a greater absorption of solar energy. As more sunlight is absorbed, temperature will continue to increase, melting even more snow and ice, leading to even more absorption.

ELABORATE

Q1. There has been an increase in the number of wildfires in the Arctic due to changes in surface temperature anomalies. Explain why the Arctic has been experiencing larger and more severe wildfires. Your answer should include information about surface temperature anomalies, albedo, Arctic amplification, and the environmental conditions favorable to wildfires.

Surface temperature anomalies have been increasing more in the Arctic when compared to other locations on Earth, leading to the melting of snow and sea ice in the region. This reduces the albedo of the surface, allowing for a greater absorption of solar energy. The region is experiencing Arctic amplification because as temperatures increase, more ice melts, leading to more absorption. This in turn causes temperature to increase more, leading to more melting and more absorption of energy. The increased temperatures also lead to drier conditions in the region, leaving environmental conditions favorable to wildfires. Additionally, the melted snow and ice exposes land surfaces such as grass, soil, etc., that can act as fuel for the wildfires.

Step 1. Below are five NASA resources related to wildfires in the Arctic.

- Link to video titled NASA Studies How Arctic Fires Change the World
- Link to NASA article titled NASA Studies How Arctic Wildfires Change the World
- Link to NASA article titled NASA's Aqua Satellite Shows Siberian Fires Filling Skies With Smoke
- Link to NASA resource titled The Study of Earth as an Integrated System that explains positive and negative feedback.
- Link to NASA Research Feature titled Another Intense Summer of Wildfires in Siberia

Utilize each resource to answer the questions below.

Q2. Why are wildfires in the Arctic an example of positive feedback?

Wildfires in the Arctic are an example of positive feedback because the fires are burning the soil, which is very rich in organic matter. As the organic matter is burned, greenhouse gases are released into the atmosphere. Greenhouse gases can further increase temperature, which enhances the conditions favorable to wildfires. Therefore, as the number of wildfires in the Arctic increase, temperatures can further increase, leading to even more wildfires.

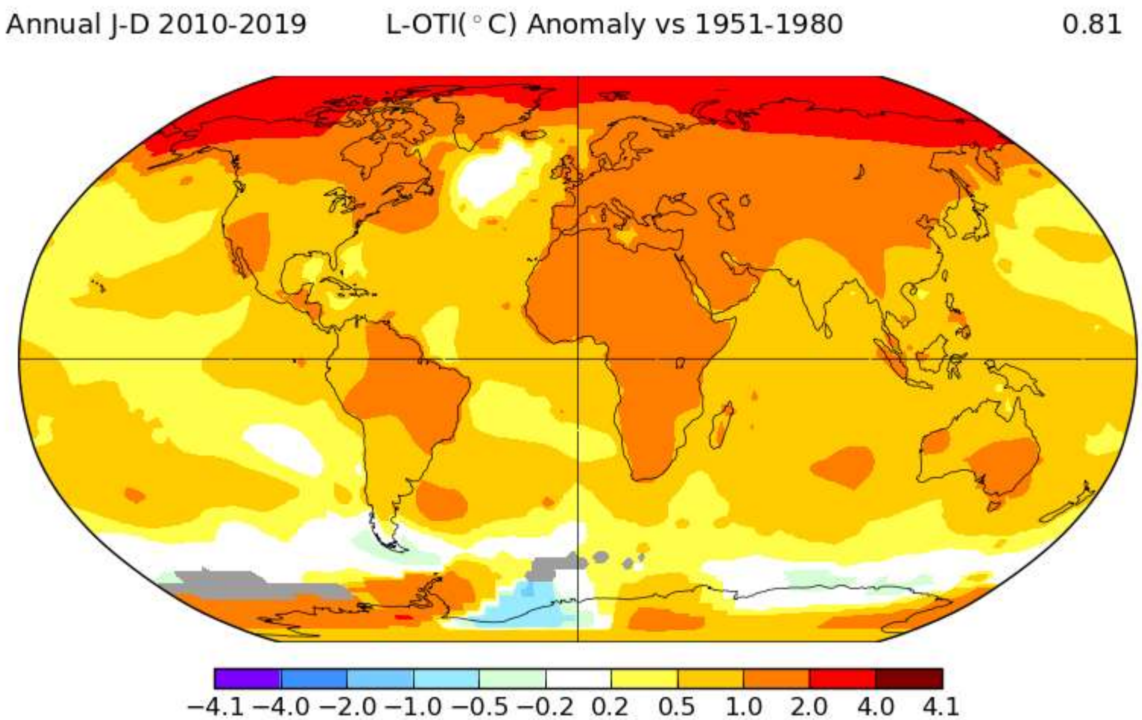
Q3. Explain why wildfires in the Arctic can lead to changes in global climate.

Wildfires in the Arctic can influence global climate because the soil in the Arctic is rich in organic matter. When this organic matter is burned, a large amount of carbon is emitted into the atmosphere, which can increase the greenhouse gas concentration of the atmosphere. As greenhouse gas concentrations increase, global temperatures can also increase.

***Wildfires in the Arctic can have a different impact on the atmosphere than wildfires in other regions of the world specifically due to the organic matter in Arctic soil.**

EVALUATE – Q3 – Q5 are adapted from the New York State Earth Science Regents.

Use the map below to answer Q1 and Q2. The map shows average global surface temperature anomalies from 2010 – 2019 from GISTEMP.



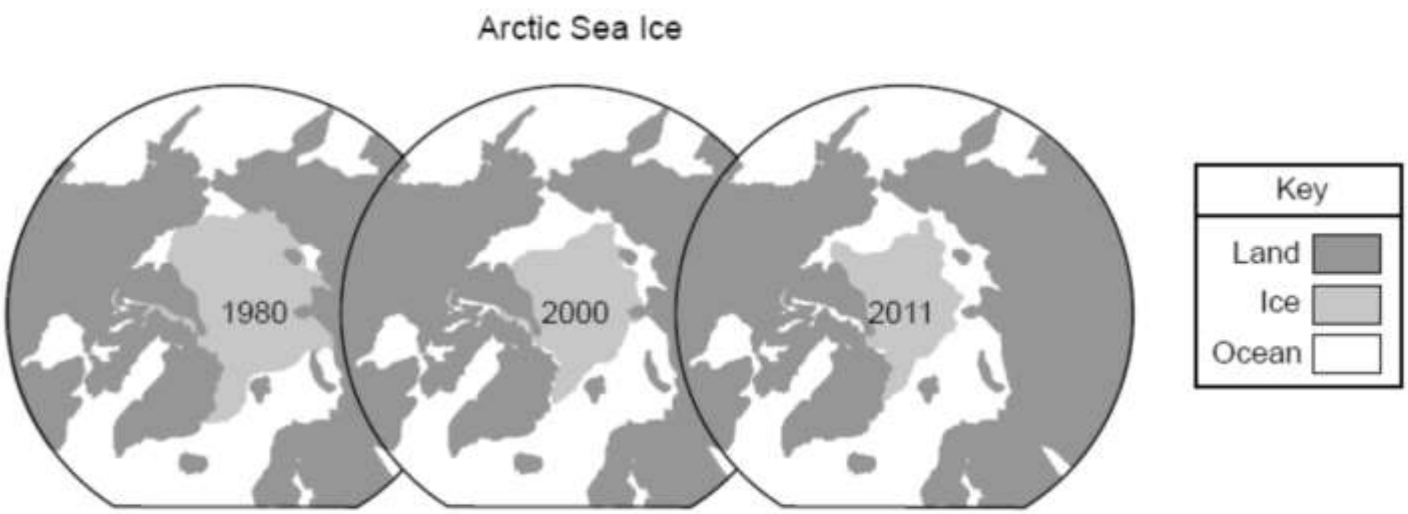
Q1. Which regions of the world have experienced a greater increase in temperature due to climate change?

The Arctic region in the high latitudes of the Northern Hemisphere experienced a greater increase in temperature.

Q2. Why are these regions experiencing a greater increase in temperature when compared to the rest of the world?

The Arctic region is experiencing a greater increase in temperature because the melting snow and sea ice leads to a decrease in the reflection of sunlight and an increase in the absorption of sunlight. This causes an increase in temperature, which leads to even more melting and absorption of energy.

Use the maps below to answer Q3 and Q5. The north polar view maps show the average area covered by Arctic Sea ice in September of 1980, 2000, and 2011. Map is from the New York State Earth Science Regents.



Q3. How has the amount of ice in the Arctic Sea changed overtime?

The amount of Arctic Sea ice has decreased overtime.

Q4. How has this change in the amount of Arctic Sea ice influenced the albedo of the Arctic?

The decrease in Arctic Sea ice has decreased the surface albedo of locations in the Arctic.

Q5. Explain how this change in Arctic Sea ice has led to Arctic amplification.

Arctic amplification is occurring because the increase in temperature is melting the snow and sea ice in the region. This reduces the albedo of the surface, allowing for a greater absorption of solar energy. As more sunlight is absorbed, temperature will continue to increase, melting even more snow and ice, leading to even more absorption.

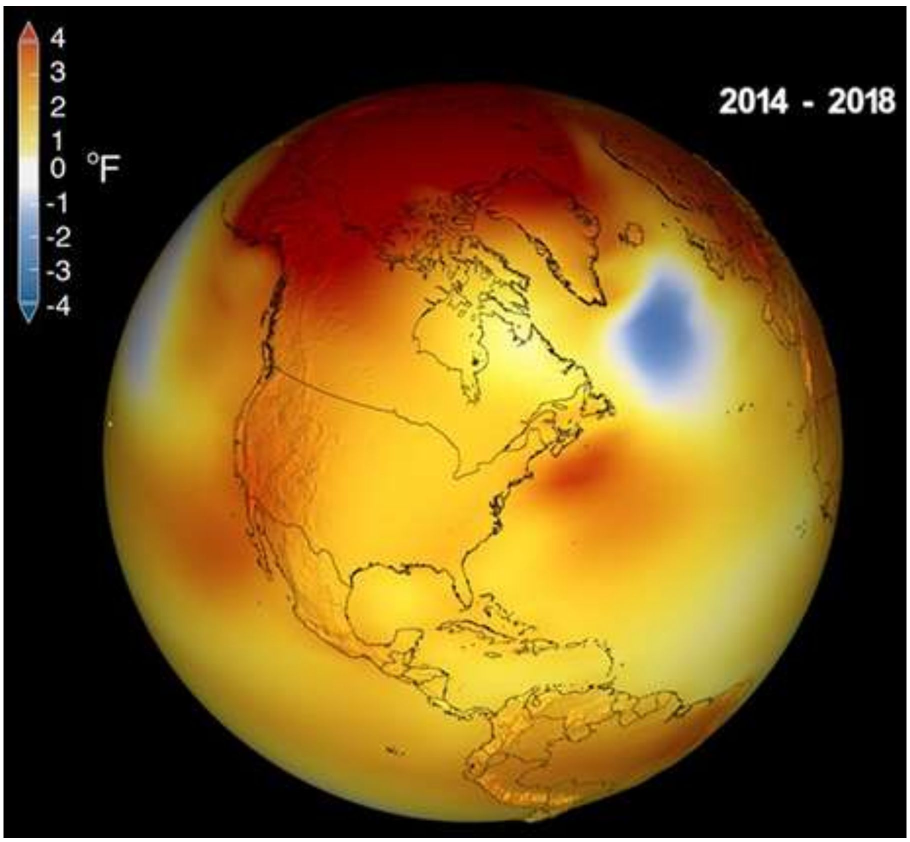
E. Conclusion and overview of linkages to next lesson and unit goals

In this lesson the students learned how the Arctic regions are warming at a greater rate when compared to the rest of the world due to Arctic Amplification. The students were able to make connections between changes in surface albedo and changes in temperature, and ultimately use this information to explain why the Arctic region has been experiencing wildfires. The content of this lesson is related to the unit's anchor phenomenon about wildfires and provides students with an example of human-induced behaviors can lead to changes in climate and the start of wildfires. In the next lesson, the students will investigate other natural events that can lead to changes in climate through the El Niño Southern Oscillation and Arctic Oscillation (AO) teleconnections. Specifically, the students will learn how the AO can impact wildfires in eastern Siberia and will end the lesson learning how ENSO can be used to predict surface temperature anomalies.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Changes in Climate & Wildfires
Lesson #4 Title: Atmospheric Teleconnections
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



XI. Lesson #4: Atmospheric Teleconnections

A. Summary and Goals of Lesson

The goal of this lesson is to have the students further explore natural events that can result in changes in climate through the El Niño Southern Oscillation (ENSO) and Arctic Oscillation (AO) teleconnections. The students were already introduced to ENSO in Lesson #2, but this lesson includes an application of ENSO in the Elaborate activity and its relationship to global surface temperature anomaly predictions. This **5E**-structured lesson is based on the following investigative phenomenon:

The change in temperature and pressure in one region of the world can influence weather patterns in another region.

The lesson begins with the **Engage** activity in which the students watch a NASA video titled El Niño Triggered Outbreaks Across the Globe. After watching the first minute of the video, the students complete a What I Know/What I Am Wondering chart and then discuss the What I Am Wondering statements with a small group. The students then watch the remainder of the video and try to come up with explanations for their statements. The students will then use their knowledge of ENSO and the information in the video to define “teleconnection”. The goal is for the students to make meaning of ENSO as a teleconnection before learning about the Arctic Oscillation.

In the **Explore** activity, the students will learn more about teleconnections as they investigate the atmospheric conditions during both phases of the Arctic Oscillation. Specifically, the students will analyze sea level pressure anomaly data and surface temperature anomaly data in Panoply to learn how pressure and temperature change in the North Atlantic Ocean and eastern Siberia during the positive and negative phases of the AO. The students will also make connections between the positive AO and environmental conditions conducive to wildfires.

In the **Explain** activity, the students will learn how both phases of the AO develop and their impacts on climate by reading a text about the AO from the National Snow & Ice Data Center. The students will make connections between both phases of the AO and climate in eastern Siberia through the lens of wildfires. The students will also create diagrams that illustrate atmospheric changes during both AO phases.

In the **Elaborate** activity, the students will use a script in the R programming language developed by NASA GISS scientists to learn how the ENSO teleconnection is related to global surface temperature anomalies. Specifically, the students will use RStudio to run a script that uses the current December/January ENSO phase to predict the current year’s and next year’s surface temperature anomaly.

In the **Evaluate** activity, the students will answer two assessment questions based on the ENSO and AO teleconnections.

B. Table of Contents for Lesson

C. 5E Lesson Model Template

5E Lesson Plan - Earth Science

Unit: Changes in Climate & Wildfires **Topic**: Atmospheric Teleconnections

Prior Learning:

The following Next Generation Science Standards (NGSS) Performance Expectations (PE), Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEP), and Cross-Cutting Concepts (CCC) should have been experienced by the students in Middle School:

- **PE**: MS-ESS2-5
  - **DCI**: ESS2.C - The Role of Water in Earth's Surface Processes
  - **SEP**: Planning and Carrying Out Investigations
  - **CCC**: Cause and Effect
- **PE**: MS-ESS2-6
  - **DCI**: ESS2.D - Weather and Climate
  - **SEP**: Developing and Using Models
  - **CCC**: Systems & Systems Models

In this lesson, the students will learn about atmospheric teleconnections. In Earth's climate system, certain patterns, or modes, of variability appear over and over again. ENSO and the Arctic Oscillation (AO) are examples of this mode variability with multiple teleconnections – or associated larger patterns of variability. The students will then use a code in the R language developed by NASA GISS scientists to investigate the ENSO teleconnection further and how it can be used to predict the current and next year's average surface temperature anomaly. The lesson is based on the following **investigative phenomenon:**

The change in temperature and pressure in one region of the world can influence weather patterns in another region.

Students will build on their knowledge of prior learning in Middle School by investigating how interactions between the ocean and atmosphere can lead to changes in atmospheric circulation, which impacts local weather and climate patterns. The students should already have knowledge of how pressure systems impact local climate and how the jet stream acts as the boundary separating cold air in the north from warmer air in the south. Prior to this lesson, the students should also have knowledge of the El Niño Southern Oscillation (ENSO) from the second lesson of this unit. If students need a review of pressure systems, go to this link to access a resource about pressure systems from UCAR.

Aim: How can changes in atmospheric conditions in one region of the world influence weather patterns in another?

Next Generation Science Standards (NGSS):

Performance Expectation:

- **HS-ESS2-2**. – Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to Earth's systems.

- **Science and Engineering Practices:**
  - Analyzing and Interpreting Data
- **Disciplinary Core Ideas**:
  - ESS2.D: Weather and Climate
- **Cross-cutting Concepts:**
  - Stability and Change

Performance Expectation:

- **HS-ESS2-4.** – Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate
  - **Science and Engineering Practices:**
    - Analyzing and Interpreting Data
  - **Disciplinary Core Ideas**:
    - ESS2.D: Weather and Climate
  - **Cross-cutting Concepts:**
    - Cause and Effect

Performance Expectation:

- **HS-ESS3-5** – Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems
  - **Science and Engineering Practices:**
    - Analyzing and Interpreting Data
  - **Disciplinary Core Ideas**:
    - ESS3.D: Global Climate Change
  - **Cross-cutting Concepts:**
    - Stability and Change

Multiple Science Domains:

This lesson contains links between the Earth and Space Science DCIs listed above and the following Physical Science DCIs:

- PS3.B Conversion of Energy and Energy Transfer
- PS4.B Electromagnetic Radiation

<u>Common Core Learning Standards (CCLS):</u>

- **11-12.RST.3** - Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

- **11-12.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

- **11-12.RST.9** - Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Performance Objective: Students will be able to investigate how the Arctic Oscillation can impact global climate by exploring sea level pressure anomaly data and surface temperature anomaly data in Panoply.

Students will be able to predict how ENSO can influence global surface temperature anomalies by writing and running a code in RStudio that establishes a relationship between the December-January phase of ENSO and the current and next year's temperature anomalies.

Materials:

- Class set of computers
- NASA Panoply software
- RStudio

Links to electronic resources are provided below:
- Link to the NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe
- Link to NASA article titled El Niño
- Link to average monthly sea level pressure anomaly data from NOAA
- Link to NASA's GISTEMP surface temperature anomaly data
- Link to UCAR source about teleconnections
- Link to Arctic Oscillation information from the National Snow & Ice Data Center
- Link to article from the NASA Earth Observatory titled Heat and Fire scorches Siberia
- Link to NOAA source about El Niño's impact on global temperature
- Link to RStudio download
- Link to NASA GISTEMP data for use in RStudio
- Link to MEI2 Index data for use in RStudio

Vocabulary:

- Anomaly
- ENSO
- Arctic Oscillation
- Teleconnection

Development of the 5E Lesson: Approximate Seven-Day Lesson (Seven 50-minute periods).

What the teacher does	What the student does	Time
1. ENGAGE Introduce the students to the ENGAGE activity and the NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe • Make sure the students only watch the first minute of the video and then complete Q1.	The students begin the ENGAGE activity by watching the first minute of the NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe. After the first minute of the video, the students complete a "What I Know", "What I am Wondering" chart based on	**1 period**

<table>
<tr><th>What the teacher does</th><th>What the student does</th><th>Time</th></tr>
<tr><td>Tell students they need to write three statements each for “What I Know” and “What I am Wondering”.
Circulate the room as the students engage in the 5-minute Turn & Discuss based on their statements in the “What I am Wondering” column.
Each student shares one statement, and then the group chooses one statement to focus on for the remainder of the discussion.
Encourage the students to use the Turn & Discuss quality criteria to guide their discussion.
At the end of the discussion, get the focus “What I Am Wondering Statement” from each group and write it on the board.
Have the students watch the remainder of the NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe
After the video, make sure each student writes down any information they learned that relates to each of the What I am Wondering focus statements written on the board.
Show students the quote about El Niño as a teleconnection and circulate as the students answer Q2 and try to define a teleconnection.

Assessment Opportunity #1 (Student prior knowledge based on their statements in the “What I Know” column).

Assessment Opportunity #2 (Student misconceptions based on their statements in the “What I am Wondering” column).

Assessment Opportunity #3 (Student definitions of a teleconnection).</td>
<td>the content. Students need to write three statements in each column.

The students engage in a Turn & Discuss with a small group based on the “What I am Wondering” statements. Each student will share one statement, and then the group will decide on one statement to focus on.

One representative from each group will share their group’s “What I am Wondering” focus statement with the class, which will be displayed on the board.

The students watch the remainder of the NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe.

For each “What I am Wondering” focus statement, the students will write down related information.

The students will evaluate the quote about El Niño as a teleconnection and try to define what a teleconnection is based on the content of the ENGAGE activity.</td>
<td></td></tr>
<tr><td>2. EXPLORE</td><td>The students download the monthly average sea level pressure anomaly data and open the data in Panoply.</td><td>1.5 periods</td></tr>
</table>

What the teacher does	What the student does	Time
Show the students how to access the monthly average sea level pressure anomaly data and open the data in Panoply. Circulate the room as the students complete the sea level pressure anomaly data portion of the EXPLORE activity. • Make sure the students are correctly centering their maps and using the correct orthographic map projection. • Check in with the students to ensure they can differentiate between the data in Region 1 and Region 2 for the Arctic Oscillation. Circulate the room as the students complete the surface temperature anomaly data portion of the EXPLORE activity. • Make sure the students correctly download the GISTEMP data and open it in Panoply. • Make sure the students reverse the color scale so that blue colors represent negative anomalies and red colors represent positive anomalies. ***Assessment Opportunity #4 (Student answers to Q1 to Q13 in the EXPLORE activity).***	The students answer Q1 to Q8 and investigate sea level pressure anomalies during the positive and negative phases of the Arctic Oscillation. The students download the monthly surface temperature anomaly data from GISTEMP and open the data in Panoply. The students answer Q9 to Q13 and investigate surface temperature anomalies during the positive and negative phases of the Arctic Oscillation.	
3. EXPLAIN Read the quote from UCAR about teleconnections in the beginning of the EXPLAIN activity. • Check in with the students to see if their definition of teleconnection has changed from the ENGAGE activity. Encourage the students to read Q4 to Q11 first before reading the text from the National Snow & Ice Data Center about the Arctic Oscillation. • Make sure the students are distinguishing between the middle North Atlantic and Arctic regions associated with the Arctic Oscillation.	The students analyze the quote from UCAR about teleconnections. The students re-define teleconnections based on the information learned in this lesson thus far. The students read the text from the National Snow & Ice Data Center about the Arctic Oscillation. The students answer Q4 to Q11 based on the text. The students use their knowledge of the Arctic Oscillation to create diagrams that show the atmospheric impacts of each phase of the AO in the North Atlantic Ocean and Siberia.	**1.5 periods**

<table>
<tr><th>What the teacher does</th><th>What the student does</th><th>Time</th></tr>
<tr><td>As the students complete Q12 to Q17, check to make sure the students are correctly differentiating between the positive and negative phases of the Arctic Oscillation.
Provide students with model diagrams from Q12 to Q17, if needed.
Q18 to Q20 are summary questions intended to check student understanding of the Arctic Oscillation.
Check in with all students to ensure their answers to these questions are correct before they can move on in the lesson.
Assessment Opportunity #5 (Student definitions of teleconnections).

Assessment Opportunity #6 (Student answers to Q4 and Q11 based on the text about the Arctic Oscillation)

Assessment Opportunity #7 (Student-created diagrams from Q13 to Q17)

Assessment Opportunity #8 (Student answers to activity summary questions Q18 to Q20).</td><td>The students answer summary questions Q18 to Q20 to demonstrate their knowledge of the Arctic Oscillation as a teleconnection.</td><td></td></tr>
<tr><td>4. ELABORATE

Please see the For Teachers Guide immediately after this lesson plan for more guidance.

Introduce the ELABORATE activity to the students. Make sure the students correctly evaluate how El Niño is historically related to higher average global surface temperature.
This is meant to remind students how and why ENSO is considered to be a teleconnection.
Circulate as the students complete the RStudio portion of the activity.
Model for the students how to accurately change the working directory.</td><td>The students analyze a graph that shows annual surface temperature from 1950 to 2017 and the relationship between ENSO phase and years with the highest temperature. This allows students to establish a relationship between ENSO and annual surface temperature as they answer Q1 to Q4.

The students begin the RStudio activity. The students write a code that establishes a relationship between the December-January phase of ENSO and the current and next year’s surface temperature anomaly.

The students evaluate the plot that resulted from their code in RStudio as they answer Q5 to Q8.</td><td>3 periods</td></tr>
</table>

What the teacher does	What the student does	Time
• Remind the students that RStudio is case sensitive, and the instructions need to be followed exactly. As the students get to step #25 of the activity, model how to use Google Sheets to create a scatter plot. **Note: There is an extension activity for higher performing students explained in Step #4 of the For Teachers Guide. ***Assessment Opportunity #9 (Student answers to Q1 – Q4).*** ***Assessment Opportunity #10 (Student-created plots in RStudio and Google Sheets).*** ***Assessment Opportunity #11 (Student answers to Q5 to Q13).***	The students use ENSO-DJ MEI2 Index data and temperature anomaly data to create a scatter plot in Google Sheets. The students further analyze the relationship between ENSO as a teleconnection and surface temperature anomalies in Q9 to Q13.	
5. EVALUATE Circulate as the students answer the EVALUATE questions. ***Assessment Opportunity #12 (Student answers to the EVALUATE questions).***	The students answer the EVALUATE questions.	**15 min**

Summary/Conclusion: The students answer the EVALUATE questions.

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them. Students will also have access to highlighters during reading activities.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.
- Students are given sentence starters to use during class discussions.

- All images and graphs have alternative text.

- Students who need extra support can join the teacher for small group instruction and more efficient feedback.

- Students who are performing at a higher level can complete the tasks provided in the For Further Exploration part of the lesson plan.

- For students who are performing well with coding and mathematical applications, there is an extension activity in the Elaborate section of the lesson plan. This extension activity is explained in Step #4 of the For Teachers Guide.

- Students with a visual impairment can receive additional guidance from a sighted teacher about the color schemes in the surface temperature anomaly and sea level pressure anomaly maps. Additionally, students have the freedom to choose a color scale in Panoply to suit their visual needs when evaluating maps.

- The closed-captioning feature on videos can be utilized to enhance the viewing experience for students.

Next Lesson: The next lesson the students will complete an assessment activity based on the knowledge gathered from lessons #1 - #4.

For Further Exploration:

1. Go to this link to learn about the current state of ENSO

2. Go to this link to learn about the current state of the Arctic Oscillation

Notes For Revision:

Supporting Documents:

1. For Teachers Guide – Elaborate Activity
2. RStudio Download Instructions
3. Temperature_Predictions.R script
4. GISTEMP_Download.R, MEI2_Download.R, and Temperature_Predictions_Source.R scripts
5. Atmospheric Teleconnections 5E Activity
6. Atmospheric Teleconnections 5E Activity Answers

D. Supporting Documents (order according to sequence of lesson)

For Teachers Guide - ELABORATE Activity

Directions: Please read this **For Teachers Guide** in entirety before completing the ELABORATE activity with the students. This guide presents helpful hints and steps teachers need to take in advance of implementing the lesson.

Step 1. Make sure that RStudio is downloaded on student computers prior to the lesson. There are instructions for accessing and downloading RStudio at the end of this For Teachers Guide.

- Here is a link to a video showing users how to download RStudio and also provides an introduction to using RStudio. This is a great resource for students and teachers to utilize if more background on R and programming is needed.

Step 2. In this lesson, the students will be writing a code in RStudio titled **Temperature_Predictions.R** The code the students are writing will download the most recent GISTEMP data and the MEI2 Index data from the internet and then load the data into RStudio. The **Temperature_Predictions.R** script will download the GISTEMP data and MEI2 Index data by sourcing two RScripts titled **GISTEMP_Download.R** and **MEI2_Download.R**.The last line of the **Temperature_Predictions.R** script sources another script titled **Temperature_Predictions_Source.R** that will be performing all of the calculations and statistical analyses.

In order for the students to create **Temperature_Predictions.R**, there are three RScripts that need to be created by the teacher and given to the students to download into the **Desktop folder on their computer**.

1. **GISTEMP_Download.R**
2. **MEI2_Download.R**
3. **Temperature_Predictions_Source.R**

These three scripts can be downloaded as a ZIP file at the following link:
https://www.giss.nasa.gov/edu/res/supplement/Dulaney_2021/R_scripts.zip

Save the scripts as **GISTEMP_Download.R**, **MEI2_Download.R**, and **Temperature_Predictions_Source.R**, respectively and then you can provide to the students to download. Please make sure the students download each script into their Desktop folder!

Each of the three scripts are also provided after the RStudio download instructions in this lesson plan.

The **Temperature_Predictions.R** script the students are creating will source each of the three scripts provided to them so they can successfully complete the activity.

Step 3. Before giving the students the **Temperature_Predictions_Source.R** script, in line #22 of the RScript, change the word TRUE to FALSE. Line #22 should look like the following:

extraplots<-FALSE # This is a flag to produce extra scatter plots associated with the predictions

Step #5 below describes a possible extension activity for students with **extraplots<-TRUE**. When set to TRUE, additional plots will be created for analysis. For simplicity in the lesson, we are setting it to FALSE.

Step 4. An example of the **Temperature_Predictions.R** script is also provided after the RStudio download instructions. This should not be given to the students.

Summary:

- The students will be writing **Temperature_Predictions.R** that downloads and reads in the GISTEMP data and the MEI2 Index data, and sources the **Temperature_Predictions_Source.R**
- The teacher will provide students with the **GISTEMP_Download.R**, **MEI2_Download.R**, and **Temperature_Predictions_Source.R** scripts.

Step 5. POSSIBLE EXTENSION FOR STUDENTS

Line #22 of **Temperature_Predictions_Source.R** gives the option for the teacher and student to create two additional plots for analysis. These extra plots can be an extension activity for students who are performing well with programming and data analysis.

- The first additional plot is a scatter plot of the average temperature anomaly of all months up until the current month (year-to-date) versus the annual average temperature anomaly of the whole year. The red line is a linear fit to the scatter plot. The blue dot has an x-axis value of the year-to-date temperature anomaly of the current year; the blue line is the uncertainty about that estimate.
- The second additional plot is a scatter plot of the actual annual average temperature anomaly on the y-axis and the predicted annual average temperature given the smoothed temperature field and the December-January ENSO index. The red line is a linear fit to the scatter plot. The blue dot has an x-axis value of the year-to-date temperature anomaly of this year; the blue line is the uncertainty about that estimate.

Below is the code written in line #22 that contains the option to print the two additional plots:

extraplots<-FALSE # This is a flag to produce extra scatter plots associated with the predictions

Currently, extraplots is set equal to FALSE, which means the two additional plots will not be created. To create the extra plots, set **extraplots<-TRUE**.

The codes **GISTEMP_Download.R** and **MEI2_Download.R** *were created by Dr. Allegra LeGrande.*

RStudio Download Instructions

Step 1. To download RStudio, the computer must have a program called R installed first. To download R, click on this link. Then, you should see a screen titled The Comprehensive R Archive Network with options to download R for the type of computer you have. This screen is shown in the image below.

The Comprehensive R Archive Network

Download and Install R

Precompiled binary distributions of the base system and contributed packages, **Windows and Mac** users most likely want one of these versions of R:

- Download R for Linux
- Download R for (Mac) OS X
- Download R for Windows

R is part of many Linux distributions, you should check with your Linux package management system in addition to the link above.

Choose the download option based on the computer you have.

Step 2. Once R is downloaded and installed, click on this link to download RStudio.

Scroll down the page and look for the heading **All Installers,** as shown in the image below.

All Installers

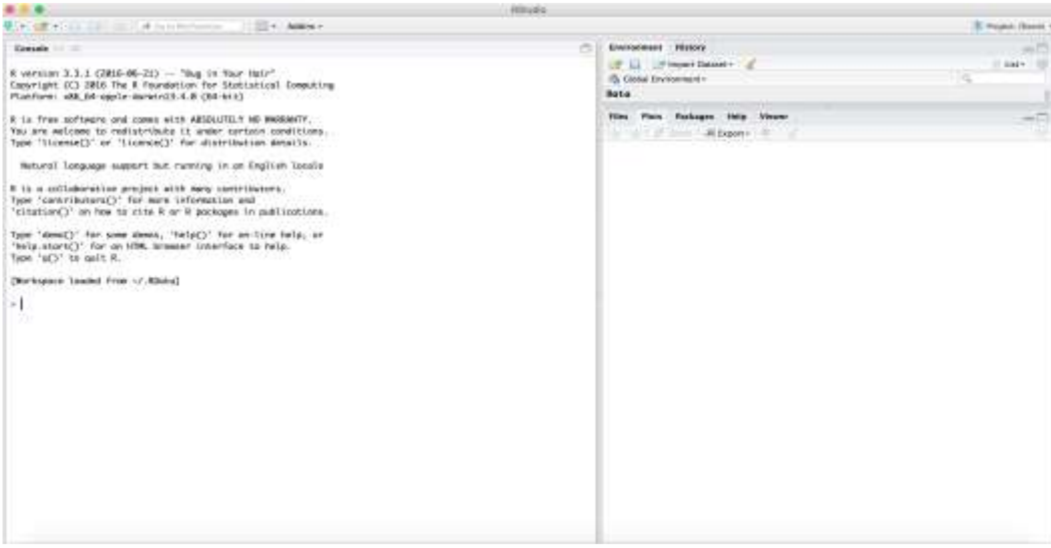
Linux users may need to import RStudio's public code-signing key prior to installation, depending on the operating system's security policy.

RStudio requires a 64-bit operating system. If you are on a 32 bit system, you can use an older version of RStudio.

OS	Download	Size	SHA-256
Windows 10/8/7	RStudio-1.3.1056.exe	171.62 MB	a8f1fee5
macOS 10.13+	RStudio-1.3.1056.dmg	148.64 MB	f343c77d
Ubuntu 16	rstudio-1.3.1056-amd64.deb	124.56 MB	cbd5e5e5
Ubuntu 18/Debian 10	rstudio-1.3.1056-amd64.deb	126.50 MB	cd1a9e17
Fedora 19/Red Hat 7	rstudio-1.3.1056-x86_64.rpm	146.86 MB	0b1576bb
Fedora 28/Red Hat 8	rstudio-1.3.1056-x86_64.rpm	150.95 MB	bc4b3f44
Debian 9	rstudio-1.3.1056-amd64.deb	126.65 MB	3fb317e5
SLES/OpenSUSE 12	rstudio-1.3.1056-x86_64.rpm	119.17 MB	1ba3540b
OpenSUSE 15	rstudio-1.3.1056-x86_64.rpm	128.14 MB	0e881257

Then, click on the option based on the computer that you have.

Step 3. When RStudio is done downloading, open the program and you should see a screen that looks like this:



If needed, please view the [video at this link for further instructions for downloading RStudio.]()

Temperature_Predictions.R

Below is an example RScript for Temperature_Predictions.R If you copy and paste the script into an RScript file, all of the proper colors will appear.

Note: This example script is here to guide teachers and should not be provided to the students!

```
library(sm)
library(gdata)

#Run the GISTEMP_Download.R and MEI2_Download.R scripts to download the gistemp_v4_mon.lp and MEI2.txt datasets for use in Temperature_Predictions_Source.R
source("GISTEMP_Download.R")
source("MEI2_Download.R")

#Source the Temperature_Predictions_Source.R script. This RScript contains the code that performs all of the calculations and makes plots for further analysis.
source("Temperature_Predictions_Source.R")
```

MEI2_Download.R

Copy and paste the code below into an RScript and save it as MEI2_Download.R This needs to be provided to the students and saved to their Desktop folder.

```
# This code was written by Allegra N. LeGrande
### Contact: Allegra.N.LeGrande@nasa.gov

### Change to your local directory as needed
localdir<-""

### I/O information
meiurl<-"https://www.esrl.noaa.gov/psd/enso/mei/data/meiv2.data"
localmei<-"meiv2.data"
foutmei<-"MEI2.txt"

########GET MEIv2##################
download.file(meiurl,destfile=paste(localdir,localmei,sep=""), quiet = TRUE)
if(!file.exists(paste(localdir,localmei,sep=""))){print(paste("PROBLEM could not
download",paste(localdir,localmei,sep=""),"from",meiurl))}

# Figure out the number of years
cdaterange <- file(paste(localdir,localmei,sep=""),"r")
seek(cdaterange,origin="start",where=0)
first_line <- readLines(cdaterange,n=1)
close(cdaterange)
len_first_line<-nchar(first_line)
mei_syear<-substr(first_line,1,4)
mei_eyear<-substr(first_line,len_first_line-3,len_first_line)
mei_nyear<-as.integer(mei_eyear)-as.integer(mei_syear) + 1

# Read in data
mei_colnames<- c("YEAR","DECJAN","JANFEB","FEBMAR","MARAPR","APRMAY","MAYJUN"
           ,"JUNJUL","JULAUG","AUGSEP","SEPOCT","OCTNOV","NOVDEC")
mei_data<-read.table(paste(localdir,localmei,sep=""),skip=1,row.names=1
             ,col.names=mei_colnames,nrows=mei_nyear,na.strings = '-999.00')

# Write out processed MEIv2 Uncomment these lines
#install.packages("gdata") ### Only needed first time
#library(gdata,warn.conflicts=FALSE)
#write.fwf(mei_data,file=paste(localdir,foutmei,sep=""),sep="   "
#       ,colnames=TRUE,rownames = TRUE,rowCol = mei_colnames[1])
```

GISTEMP_Download.R

Copy and paste the code below into an RScript and save it as GISTEMP_Download.R This needs to be provided to the students and saved to their Desktop folder.

```
# This code was written by Allegra N. LeGrande
### Contact: Allegra.N.LeGrande@nasa.gov

### Change to your local directory as needed
localdir<-""

### I/O information
gistempurl<- "https://data.giss.nasa.gov/gistemp/tabledata_v4/GLB.Ts+dSST.txt"
gistlocal<-"GLB.Ts+dSST_v4.txt"
gistfout<-"gistemp_v4_mon.lp"

######### GET GISTEMP##########
# Download data
download.file(gistempurl,destfile=paste(localdir,gistlocal,sep=""), quiet = TRUE)
if(!file.exists(paste(localdir,gistlocal,sep=""))){print(paste("PROBLEM could not
download",paste(localdir,gistlocal,sep=""),"from",gistempurl))}

# Figure out the number of years and set up date arrays
gistrange <- file(paste(localdir,gistlocal,sep=""),"r")
tmp<-seek(gistrange,origin="start",where=0)
gist_period<-readLines(gistrange,n=1)
tmp<-readLines(gistrange,n=1) # skip first two lines
gist_line <- readLines(gistrange,n=1)
tmp<-readLines(gistrange,n=4) # skip next four lines
gist_lincolumn<- readLines(gistrange,n=1)
gist_columns <- strsplit(gist_lincolumn, "\\s+")[[1]] # GISTEMP Column Labels
gist_columns[1]<-paste("r",gist_columns[1],sep="")
close(gistrange)

len_gist_period<-nchar(gist_period)
gist_base_syear<-substr(gist_period,len_gist_period-8,len_gist_period-5) # Base Start Year
gist_base_eyear<-substr(gist_period,len_gist_period-3,len_gist_period) # Base End Year
tmp<-regexpr("degrees",gist_period) # scaling factor
gist_scale<-as.numeric(substr(gist_period,tmp[[1]]-5,tmp[[1]]-2))

len_gist_line<-nchar(gist_line)
gist_syear<-substr(gist_line,len_gist_line-11,len_gist_line-8) # Start Year
gist_eyear<-substr(gist_line,len_gist_line-3,len_gist_line) # End Year
```

```
gist_nyear<-as.integer(gist_eyear)-as.integer(gist_syear) + 1
gist_dates<-seq(as.integer(gist_syear)+1/24,as.integer(gist_eyear)+1,1/12)
gist_year1d=array(data=NA,dim=c(length(gist_dates),2))
colnames(gist_year1d)<-c("date","temperature_anomaly (degC)")
rownames(gist_year1d)<-as.character(round(gist_dates,2))
gist_year1d[,1]<-round(gist_dates,2)

gist_setnum<-20 # data file is in sets of years to facilitate easy text reading
gist_nsets<-ceiling((gist_nyear-1)/gist_setnum)
gist_setl=array(data=gist_setnum,dim=c(gist_nsets))
gist_setl[1]<-gist_setnum+1
gist_setl[gist_nsets]<-(gist_nyear-1)-gist_setnum*(gist_nsets-1)

# Read in data; complicated because it is in clusters
gist_array=array(data=NA,dim=c(gist_nyear,length(gist_columns)-1))
colnames(gist_array)<-gist_columns[2:length(gist_columns)]
rownames(gist_array)<-as.character(seq(gist_syear,gist_eyear,1))
gist_months<-gist_columns[2:13]
skip2<-0
for (n in 1:gist_nsets) {
 skip1<-skip2+1
 nskips<-6+skip2+2*n
 skip2<-skip1+gist_setl[n]-1
 gist_temp<-read.table(paste(localdir,gistlocal,sep=""),skip=nskips
            ,row.names=1,col.names = gist_columns
            ,nrows=gist_setl[n],na.strings = c('****','***'))
 gist_array[skip1:skip2,]<-array(as.numeric(unlist(gist_temp)), dim=dim(gist_temp)) # Convert R list to array
}
dim(gist_array)[2]
gist_array<-gist_array[,1:dim(gist_array)[2]-1]*gist_scale # Apply scaling factor (from header information), but
not to last year column

# Rearrange array of year by month into a vector
gist_ct<-0
for (yr in 1 : gist_nyear ) {
 for (mn in 1:12){
  gist_ct=gist_ct+1
  if(!is.na(gist_array[yr,mn])) {
   gist_year1d[gist_ct,2]<-gist_array[yr,mn]
  }
  #uncomment to debug
  #   print(paste(gist_ct,gist_months[mn],gist_array[yr,19]
  #          ,gist_dates[gist_ct],gist_year1d[2,gist_ct],sep=" "))
 }}
```

```
# Transform from arrays to lists (which contain meta-data)
gist_data<-as.data.frame.array(gist_array)
gist_yeardata<-as.data.frame.array(gist_year1d)

# Write out processed GISTEMP Uncomment these lines
#install.packages("gdata") ### Only needed first time
#library(gdata,warn.conflicts=FALSE)
#gishead1<-"GISTEMP Global-Mean Surface Temperature"
#gishead2<-"Temperature Anomaly (\u00b0C)"
#gishead3<-" "
#gishead4<-"Year Monthly_Mean_(GHCN4)"
#write(c(gishead1,gishead2,gishead3,gishead4), file=paste(localdir,gistfout, sep=""),
#     append=FALSE)
#write.fwf(gist_yeardata,file=paste(localdir,gistfout,sep=""),sep="   "
#        ,na="****" ,colnames=FALSE,rownames = FALSE,rowCol = "year",append=TRUE)
```

Temperature_Predictions_Source.R

Copy and paste the code below into an RScript and save it as Temperature_Predictions_Source.R This needs to be provided to the students and saved to their Desktop folder.

```
### This code was principally written by Gavin A. Schmidt
### This code has been altered by N. Dulaney and Allegra N. LeGrande
### Contact: Allegra.N.LeGrande@nasa.gov

args <- commandArgs(trailingOnly = TRUE)

### Some print outs to help decide if plots should be to a file or screen
if(is.na(args[1])) {
  savepdf<-0 ## No you do not want to save output to a pdf file
  print("The plot may be saved to a pdf file by either")
  print("   changing the above line to :")
  print("                    savepdf<-1")
  print("Then re-running this script")
  print("Or from your computer's command line::")
  print("        Rscript Temperature_Predictions_Source.R 1")
} else
{
  savepdf<-1 ## Yes, you do want to save output to a pdf file?
  foutpdf<-"temperature_prediction_GISTEMP_ENSO.pdf"
}

extraplots<-TRUE # This is a flag to produce extra scatter plots associated with the predictions

source("GISTEMP_Download.R")

#Create a plot that shows the global average surface temperature anomaly, 10-year Loess smooth curve, and the 2020 and 2021 surface temperature anomaly predictions based on ENSO-DECJAN.
# savepdf<-1 means this writes a PDF file; any other value means it prints to screen
if(savepdf==1){
  pdf(paste(localdir,foutpdf,sep=""))
  print(paste("Wrote graph to: ",localdir,foutpdf,sep=""))
}

#Set Up New Variables
GISS_Anomaly_Data<-gist_year1d

#The following lines establish the start year of the data and the end year of the data (should be up to date with year to date)
```

Start_Year<-as.integer(gist_syear)#floor(GISS_Anomaly_Data[1,1]) #This takes the first value in the first column, which is the first date provided. The function floor is used to round it to the lowest and nearest whole number
End_Year<-as.integer(gist_eyear)#floor(GISS_Anomaly_Data[dim(GISS_Anomaly_Data)[1],1]) #This takes the last value in the first column, which is the last date provided. The function floor is used to round it to the lowest and nearest whole number.

#Identify the start and end years of the base period. A base period is the period of time that the temperatures will be compared to.
Base_StartYear<-as.integer(gist_base_syear) #1951 #This establishes the start year of the base period.
Base_EndYear=as.integer(gist_base_eyear) #1980 #This establishes the end year of the base period.

# Two ways to figure out the Base Mean
mon=c("Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec")
monthsPeryear<-length(mon)
index_base_syear<-1+(Base_StartYear-Start_Year)*monthsPeryear
index_base_eyear<-(1+Base_EndYear-Start_Year)*monthsPeryear
Base_Mean<-mean(GISS_Anomaly_Data[index_base_syear:index_base_eyear,2])
#Calculate the mean of the base period
Base_Mean=mean(GISS_Anomaly_Data[GISS_Anomaly_Data[,1] > Base_StartYear & GISS_Anomaly_Data[,1] < Base_EndYear+1,2]) #This calculation establishes the mean of the base period. This line is saying to take the mean of GISS_Anomaly_Data, but specifically only for years greater than the start of the base period & less than the end of the base period +1 for all anomaly values. The result is Base_Mean, which is one value as the calculated mean.
Base_Mean<-round(Base_Mean,6) # The input data has 3 significant digits, we'll impose a max of twice that here

#Calculate the anomaly of each month in the data compared to the average anomaly of the base period
We already have confirmed that the Base_Mean==0, so this next step is redundant, but a good check that we are looking at an anomaly dataset
GISS_Anomaly_Data[,2]=GISS_Anomaly_Data[,2]-Base_Mean #This is calculating the temperature anomaly for each month of the dataset based on the base period. Base_Mean is the average value of the base period and that value needs to be subtracted from all of the temperature anomaly values from all years, which is denoted by GISS_Anomaly_Data[,2]

#This calculates the current month in the current year for the last value in the dataset. This allows us to provide the most up to date month and year since GISTEMP is always updating.
index_current_year<-1+(End_Year-Start_Year)*monthsPeryear
Current_MonYear<-sum(!is.na(GISS_Anomaly_Data[index_current_year:(index_current_year+monthsPeryear-1),2])) #count months with actual values

# Pull the Annual Averages from the data file and calculate the January - this month's average for each year
Years=Start_Year:(End_Year-1) #Creates a list of all of the years in the dataset from the start year to the year before the end year

```
Annual_Avg_Current<-head(round(rowMeans(gist_array[,1:12],na.rm=TRUE),2),-1) # Average of January to December for each year (i.e., the annual average) gist_array readin in source code at top
if (Current_MonYear== 1){Annual_Avg_YTD<-gist_array[,1:Current_MonYear]}else{
Annual_Avg_YTD<-round(rowMeans(gist_array[,1:Current_MonYear],na.rm=TRUE),2)} # Average of January to current month for each year

##########################################################################################
#NOW WE WILL PREDICT THE ANNUAL AVERAGE (Annual_Avg_Current) from the Annual_Avg_YTD
##########################################################################################
# linear regression btw Annual_Avg_Current and Annual_Avg_YTD
ytd1=Annual_Avg_YTD[1:(End_Year-Start_Year)]
fred0=lm(Annual_Avg_Current ~ ytd1)
pred0=predict(fred0,newdata=data.frame(ytd1=Annual_Avg_YTD[End_Year-Start_Year+1]),se.fit=TRUE,interval="prediction")

print(paste("Previous max(es) (",Years[Annual_Avg_Current==max(Annual_Avg_Current)],"):",round(max(Annual_Avg_Current),2)))
print(paste(End_Year,"prediction based on YTD vs. Annual average regression",round(mean(pred0$fit[1]),2),"+/-",round(pred0$fit[3]-pred0$fit[1],2),"ÂºC" ))


if(extraplots){
layout(matrix(c(1,2,3,3), 2, 2, byrow = TRUE),heights =c(1,2)) # This makes 3 subplots with two on top, one on bottom
# To see this regression graphically; it appear in the upper left panel
#NB that the prediction function calculates the values for the final year based on the fred0 coefficients; i.e., pred0$fit[1] == Annual_Avg_YTD[End_Year-Start_Year+1]*fred0$coefficients[2]+fred0$coefficients[1]
plot(ytd1,Annual_Avg_Current,xlab=paste("Jan to",mon[Current_MonYear],"Avg. Temperature Anomaly (ÂºC)"),ylab="Ann Avg Temp Anomaly (ÂºC)",main=paste("Year to date avg. Vs. Annual avg.\n",Start_Year," to ",End_Year-1),xlim=c(min(ytd1,na.rm=TRUE),1.2*max(ytd1,na.rm=TRUE)),ylim = c(min(Annual_Avg_Current,na.rm=TRUE),1.2*max(Annual_Avg_Current,na.rm=TRUE)))
# Use the linear model to plot a line
a<-seq(min(ytd1,na.rm=TRUE),max(ytd1,na.rm=TRUE),.1)
b<-fred0$coefficients[1]+a*fred0$coefficients[2]
lines(a,b,col="red",lwd=3)
# Predicted value for current year
points(Annual_Avg_YTD[End_Year-Start_Year+1],Annual_Avg_YTD[End_Year-Start_Year+1]*fred0$coefficients[2]+fred0$coefficients[1],pch=16,col="blue")
lines(c(Annual_Avg_YTD[End_Year-Start_Year+1],Annual_Avg_YTD[End_Year-Start_Year+1]),Annual_Avg_YTD[End_Year-Start_Year+1]*fred0$coefficients[2]+fred0$coefficients[1]+round(pred0$fit[3]-pred0$fit[1],2)*c(-1,1),col="blue",lwd=3)
legend("topleft",col=c("black","red","blue"),cex=0.7,pch=c(1,NA,16),lwd=c(NA,3,3),legend=c("Temperatures each year","linear model fit",paste(End_Year,"Prediction")),box.lwd=0, bg="transparent")
```

```
} else{par(mfrow=c(1,1))}
#######################################################################################
#############################################
#THIS PART OF THE CODE USES THE LOESS SMOOTHING TECHNIQUE & ULTIMATELY PREDICTS THE CURRENT YEAR'S TEMPERATURE ONLY USING LOESS SMOOTHING
#######################################################################################
#############################################

#Use the loess smooth method on the annual temperature anomaly data
sm=10 #This is the number of years for smoothing
Annual_Avg_Current_sm=loess(Annual_Avg_Current ~ Years,span=2*sm/(End_Year-Start_Year),control = loess.control(surface = "direct"))

#Calculate residual fluctuations
Annual_Avg_Current_res=Annual_Avg_Current-Annual_Avg_Current_sm$fitted

#Make predictions for the current year's temperature using the loess smoothing method
Prediction_sm=predict(Annual_Avg_Current_sm,newdata=data.frame(Years=End_Year),se.fit=TRUE,interval="prediction")

#####################################################################################
#####################################################################################
########################################################################
#THIS NEXT PART OF THE CODE READS IN THE MEI2 DATA (ENSO DATA), CREATES A SUBSET FOR NON-VOLCANICALLY ACTIVE YEARS, AND THEN USES THE NON-VOLCANICALLY ACTIVE YEARS TO CREATE A SUBSET OF Annual_Avg_Current_res FROM 1979 ONNWARD, DENOTED Annual_Avg_NonVolcanicYears_res
#NEXT, CREATE A SUBSET OF ENSO_MEI_NONVOLCANIC TO INCLUDE ONLY THE DECEMBER-JANUARY (DJ) VALUES OF THE DATA, DENOTED ENSO_MEI_DJ_NONVOLCANIC
#THEN, USE THE SUBSET OF Annual_Avg_NonVolcanicYears_res to perform a linear regression with ENSO_MEI_DJ_NONVOLCANIC
#FINALLY, USE THE ENSO MEI VALUE FOR THE CURRENT YEAR BASED ON THE PREVIOUS YEAR'S DJ ENSO MEI VALUE
#####################################################################################
#####################################################################################
########################################################################

#MEI data (only available from the year 1979 onwards). MEI is abbreviated from Multivariate ENSO Index. This data contains 12 bi-monthly seasons such as Dec/Jan, Jan/Feb, Feb/Mar, etc. Therefore, each year contains 12 bi-monthly values for MEI in the ENSO region. Values greater than 0.5 indicate El NiÃ±o, while values less than -0.5 indicate La NiÃ±a.
#The MEI2 data is read in from the Temperature_Predictions.R dataset

source("MEI2_Download.R")
MEI2_Data<-array(as.numeric(unlist(mei_data)), dim=dim(mei_data)) # Convert R list to array
```

```
# How the MEI data compares to the GISTEMP
MEI_Years<-as.numeric(rownames(mei_data))
index_MEI_SYEAR<-MEI_Years[1]-Start_Year
MEI_Current_MonYear<-sum(!is.na(MEI2_Data[length(MEI_Years),]))
MEI_index_DECJAN<-which(grepl("DECJAN",names(mei_data)))

#Establishes a year as the last year in the MEI2 dataset. This will change as the MEI2.txt data is continually updated
ENSO_End_Year=dim(MEI2_Data)[1]

#Create a subset of data that leaves out volcanically active years (1984, 1992, 1993) and also leaving out last year of the data
ENSO_VolcanicYears<-which(grepl("1984|1992|1993",rownames(mei_data)))
ENSO_NonVolcanicYears<-head(which(!grepl("1984|1992|1993",rownames(mei_data))),-1)

#Create a subset of the MEI2_Data to only include the years and MEI values of the non-volcanically active years
ENSO_MEI_NonVolcanic=MEI2_Data[ENSO_NonVolcanicYears,]

#Create a subset of the residual calculations (Annual_Avg_Current_res) for just the years that were non-volcanically active, after the year 1979
Annual_Avg_NonVolcanicYears_res=Annual_Avg_Current_res[ENSO_NonVolcanicYears+index_MEI_SYEAR]
#The index_MEI_SYEAR starts the indexing for Annual_Avg_Current_res at the year 1979 to correspond to the years available for the ENSO MEI values

#Conduct a linear regression between Annual_Avg_NonVolcanicYears_res and December/January ENSO_MEI_NONVOLCANIC for only non-volcanically impacted years
#First create a subset for the MEI values of ENSO_MEI_NONVOLCANIC for just the December-January data (denoted as DJ)
ENSO_MEI_DJ_NonVolcanic=ENSO_MEI_NonVolcanic[,2] #Takes just the DJ MEI values from ENSO_MEI_NONVOLCANIC, which is the DJ MEI data from the non-volcanic years only
#Perform the linear regression between Annual_Avg_Current_res and ENSO_MEI_DJ_NonVolcanic
ENSO_Regression=lm(Annual_Avg_NonVolcanicYears_res ~ ENSO_MEI_DJ_NonVolcanic)
#Calculate the variance (r^2 value)
r2=cor(Annual_Avg_NonVolcanicYears_res,ENSO_MEI_DJ_NonVolcanic)^2
#Print the correlation coffiecient that represents the correlation between the annual average temperature anomaly from GISTEMP and the DJ ENSO MEI values, only for the non-volcanic years
#print(cor(Annual_Avg_NonVolcanicYears_res,ENSO_MEI_DJ_NonVolcanic))

#Predict the ENSO MEI value for the current year based on the most recent year's ENSO MEI value
Predict_ENSO_CurrentYear=predict(ENSO_Regression,newdata=data.frame(ENSO_MEI_DJ_NonVolcanic=MEI2_Data[ENSO_End_Year,MEI_Current_MonYear]),se.fit=TRUE,interval="prediction")
#Predict the ENSO MEI value for the current year based on the previous year's DJ ENSO MEI value
```

```
Predict_ENSO_CurrentYear=predict(ENSO_Regression,newdata=data.frame(ENSO_MEI_DJ_NonVolcanic=MEI2_Data[ENSO_End_Year,MEI_index_DECJAN]),se.fit=TRUE,interval="prediction")

###################################################################################################################################################################
#FIRST, CREATE A SUBSET DENOTED GISTEMP_Model THAT CONTAINS JUST THE FITTED VALUES FROM THE LOESS SMOOTHING (Annual_Avg_Current_sm$fitted) FROM YEAR 1979 ONWARD
#NEXT, COMBINE THESE VALUES FOR THE NON-VOLCANIC YEARS WITH THE FITTED VALUES FROM THE ENSO_REGRESSION TO CREATE AN UPDATED GISTEMP_Model
#NEXT, PERFORM A LINEAR REGRESSION BETWEEN Annual_Avg_Current (JUST 1979 ONWARD) AND GISTEMP_Model (ALREADY JUST 1979 ONWARD), DENOTED fred1
#NEXT, USE fred1 TO PREDICT THE CURRENT TEMPERATURE ANOMALY
###################################################################################################################################################################

#Create a subset called GISTEMP_Model that consists of the fitted values from the loess smoothing for the years 1979 onward of the data (to correspond to the years that the MEI2 data is available)
GISTEMP_Smooth=Annual_Avg_Current_sm$fitted[index_MEI_SYEAR:length(Annual_Avg_Current)] #Index value 99 represents year 1979
GISTEMP_Model<-GISTEMP_Smooth
#Modifies GISTEMP_Model to include the smoothed data and ENSO-related pertubations. This is done by adding GISTEMP_Model (Annual_Avg_Current_sm$fitted) during only the non-volcanic years after 1979 to the ENSO_Regressions$fitted
for (i in 1:(length(Annual_Avg_Current)-index_MEI_SYEAR-length(ENSO_VolcanicYears)))
{GISTEMP_Model[ENSO_NonVolcanicYears[i]]=GISTEMP_Smooth[ENSO_NonVolcanicYears[i]]+ENSO_Regression$fitted[i]}

# NA out the volcano affected yrs
GISTEMP_Model[ENSO_VolcanicYears]=NA

#Use GISTEMP_Model and Annual_Avg_Current to predict the temperature anomaly using a lm, linear model
fred1=lm(Annual_Avg_Current[index_MEI_SYEAR:length(Annual_Avg_Current)] ~ GISTEMP_Model)
pred1=predict(fred1,newdata=data.frame(GISTEMP_Model=Predict_ENSO_CurrentYear$fit[1]+Prediction_sm),se.fit=TRUE,interval="prediction")

#Creates and prints a statement to tell the user the prediction of the current year's annual temperature anomaly from GISTEMP based on the ESNO-DJ value
print(paste(End_Year," prediction (based on ENSO in Dec/Jan):",round(mean(pred1$fit[1]),2),"+/-",round(pred1$fit[3]-pred1$fit[1],2),"ÂºC" ))

if(extraplots){
# To see this regression / fit graphically, it will appear in the upper right panel
plot(GISTEMP_Model,Annual_Avg_Current[index_MEI_SYEAR:length(Annual_Avg_Current)],xlab=paste("Model (smooth GISTEMP + DECJAN ENSO)\n Avg. Temperature Anomaly (ÂºC)"),ylab="Ann Avg Temp Anomaly
```

```
(ÂºC)",main=paste("Model (smooth GISTEMP+DECJAN ENSO)\n Vs. Annual Avg.",as.integer(mei_syear)," to
",as.integer(mei_eyear)-
1),xlim=c(min(GISTEMP_Model,na.rm=TRUE),max(GISTEMP_Model,na.rm=TRUE)),ylim=c(min(Annual_Avg_Cu
rrent[index_MEI_SYEAR:length(Annual_Avg_Current)],na.rm=TRUE),1.2*max(Annual_Avg_Current[index_MEI
_SYEAR:length(Annual_Avg_Current)],na.rm=TRUE)))
# Use the linear model to plot a line
a<-seq(min(GISTEMP_Model,na.rm=TRUE),max(GISTEMP_Model,na.rm=TRUE),.1)
b<-fred1$coefficients[1]+a*fred1$coefficients[2]
lines(a,b,col="red",lwd=3)
#predicted value for current year
points(Predict_ENSO_CurrentYear$fit[1]+Prediction_sm,Predict_ENSO_CurrentYear$fit[1]+Prediction_sm*fre
d1$coefficients[2]+fred1$coefficients[1],pch=16,col="blue")
lines(c(Predict_ENSO_CurrentYear$fit[1]+Prediction_sm,Predict_ENSO_CurrentYear$fit[1]+Prediction_sm),Pre
dict_ENSO_CurrentYear$fit[1]+Prediction_sm*fred1$coefficients[2]+fred1$coefficients[1]+round(pred1$fit[3]-
pred1$fit[1],2)*c(-1,1),col="blue",lwd=3)
legend("topleft",col=c("black","red","blue"),cex=0.7,pch=c(1,NA,16),lwd=c(NA,3,3),legend=c("Temperatures
each year","linear model fit",paste(End_Year,"Prediction")),box.lwd=0, bg="transparent")
}
#Rough estimate of a 97.5 percent confidence:: 1.96 is the approximate value of the 97.5 percentile point of
the standard normal distribution.
conf_97p5<-1.96

#Estimate the likelihood by usina a (norm)al distribution of a (r)andom variable
number_of_temperature_obs<-1000 # This is a very rough guess
mean_of_DF_GISTEMP<-pred1$fit[1]
sd_of_DF_GISTEMP<-abs(pred1$fit[2]-pred1$fit[1])/conf_97p5
ENSO_MEI_DJ_NonVolcanic_Norm<-
rnorm(number_of_temperature_obs,mean_of_DF_GISTEMP,sd_of_DF_GISTEMP)

#Estimate global temp delta
pred2=predict(ENSO_Regression,newdata=data.frame(ENSO_MEI_DJ_NonVolcanic=ENSO_MEI_DJ_NonVolcan
ic_Norm),se.fit=TRUE,interval="prediction")

#Estimate smooth component for next year
predsmnxt=predict(Annual_Avg_Current_sm,newdata=data.frame(Years=End_Year+1),se.fit=TRUE,interval="p
rediction")

#Put together GISTEMP_Model and estimate Annual_Avg_Current
pred3=predict(fred1,newdata=data.frame(GISTEMP_Model=pred2$fit[,1]+predsmnxt),se.fit=TRUE,interval="p
rediction")

#Combine uncertainty in ENSO MEI DJ with spread from GISTEMP_Model fit
spreadnxt=sqrt(sd(pred3$fit[,1])^2 + (mean(pred3$fit[,3]-pred3$fit[,1])/conf_97p5)^2)
```

```
print(paste(End_Year+1," prediction (based on projected ENSO in Dec/Jan):",round(mean(pred3$fit[,1]),2),"+/-
",round(spreadnxt*conf_97p5,2),"ÂºC" ))

#### To see the Time Series of temperatures with the predicted 2021 and 2022 values Graphically; this
appears on the bottom
# Plot colors
mycols<-c("black","salmon","dodgerblue2","darkgreen")
year_range<-c(1980,End_Year+2)
#Plots the annual average global surface temperature anomaly
plot(Years[1:length(Annual_Avg_Current)],Annual_Avg_Current,type="o",pch=16,col=mycols[1],lwd=2,main=p
aste("Using ENSO-DECJAN to Predict Global Mean Temperature in ",End_Year," and
",End_Year+1,sep=""),xlab="Years",ylab="Anomaly (ÂºC) w.r.t. 1951-
1980",xlim=year_range,xaxs="i",ylim=c(min(Annual_Avg_Current) + 0.2,max(Annual_Avg_Current) + 0.4))
#Plots the 10-year Loess smoothing curve
lines(Years[1:length(Annual_Avg_Current)],Annual_Avg_Current_sm$fitted,col=mycols[2],lwd=4)
#Plots a point to represent the value of the average surface temperature anomaly prediction for the current
year based on the previous ENSO-DECJAN value
points(End_Year-0.25,pred1$fit[1],pch=16,col=mycols[3])
lines(c(End_Year-0.25,End_Year-0.25),pred1$fit[2:3],col=mycols[3],lwd=3)
#Plots a point to represent the value of the average surface temperature anomaly prediction for the next year
based on the projected ENSO-DECJAN phase
points(End_Year+1,mean(pred3$fit[,1]),pch=16,col=mycols[4])
lines(c(End_Year+1,End_Year+1),mean(pred3$fit[,1])+conf_97p5*spreadnxt*c(-1,1),col=mycols[4],lwd=3)

#Create a legend for the plot
legend(year_range[1]+1,(max(Annual_Avg_Current)+0.4),col=mycols,legend=c("GISTEMP Global Mean Surface
Temperature Anomaly",paste(sm,"yr Loess smooth"),paste(End_Year,"Prediction using ENSO in previous
Dec/Jan"),paste(End_Year+1,"Prediction based on projected ENSO in
Dec/Jan")),text.col=c(1,2,4,"#43592C"),lwd=c(3,3,3,3),pch=c(16,NA,16,16),box.lwd=0, bg="transparent")

par(mfrow=c(1,1)) # go back to one plot per page

if(savepdf==1){
  tmp<-dev.off() # Close file if saving to a pdf
}
```

Atmospheric Teleconnections Activity

Investigative Phenomenon – The change in temperature and pressure in one region of the world can influence weather patterns in another region.

ENGAGE

Step 1. Go to this link to watch the NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe. Scroll down towards the middle of the page to access the video. **Watch only the first minute.** While watching the video, write down any questions you have about the information presented.

Q1. Complete the chart below to demonstrate what you already know about the information in the first minute of the video, and what you are still wondering about the information. A strong response would include at least three **What I Know** statements, and three **What I am Wondering** statements. There is space for more statements, if needed!

What I Know	What I am Wondering
•	•
•	•
•	•
•	•

Step 2. With your small group, engage in a 5-minute Turn & Discuss based on the statements in the **What I am Wondering** column from Q1. Use the following guidelines during your discussion:

- Each group member will take turns sharing one statement from their **What I am Wondering** column.

- After each group member shares, the group will choose one of the **What I am Wondering** statements to focus on. This statement can be one that was repeated by more than one student, or a statement that intrigues the group the most!
- Use the remaining time to discuss the statement your group chose.

Use the Turn & Discuss Quality Criteria to help guide your discussion.

Step 3. One member from each group will share their groups' focus statement from step #2 with the class. Each **What I am Wondering focus** statement will be written on the board for the remainder of the ENGAGE activity.

Step 4. Go back and watch the remaining part of the video. After the video, use the space below to write down any information that relates to the **What I am Wondering focus** statements written on the board. You may use additional paper, if needed.

- ____

  ____

  ____

- ____

  ____

  ____

- ____

  ____

  ____

- ____

  ____

  ____

- ____

  ____

  ____

Q2. The following is a quote from a NASA article titled El Niño, which can be accessed at this link.

"El Niño is the largest natural disruption to the Earth system, with direct impacts across most of the Pacific Ocean. Indirect impacts reverberate around the globe in patterns that scientists refer to as "teleconnections.""

El Niño and the other phases of ENSO are not the only phenomena considered to have "teleconnections". Based on the quote and your knowledge of the widespread impacts of El Niño, explain what you think the meaning of the term "teleconnection" is.

____

____

____

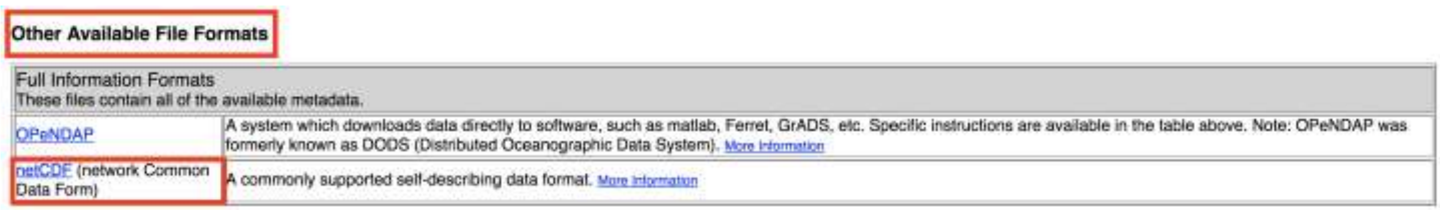
____

EXPLORE

Step 1. In this part of the activity you will be exploring another teleconnection known as the Arctic Oscillation (AO). The AO can be measured by the strength of low-pressure and high-pressure systems within the northern Atlantic Ocean.

Step 2. [Go to this link to access monthly average sea level pressure anomaly data from NOAA.]() Then, look for the section titled **Other Available File Formats** and click on the link titled **netCDF** as shown in the image below. This will download global average sea level pressure (SLP) anomaly data from January 1949 to June 2020*. The dataset contains 858 time slices, one for each month between January 1949 and June 2020*.

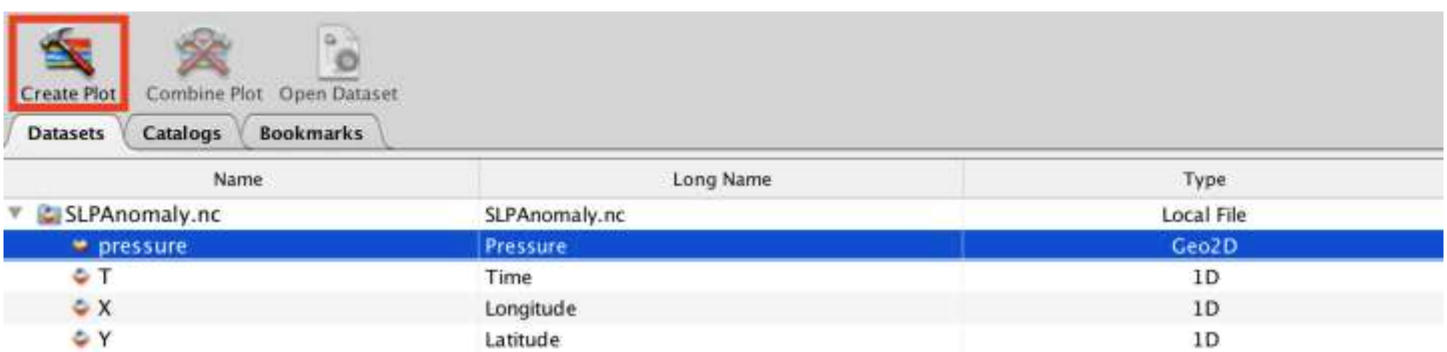
*__Note__: At the time this activity was created, the data was updated as of June 2020. As more time passes, the last month and year of the dataset will change to a later time.



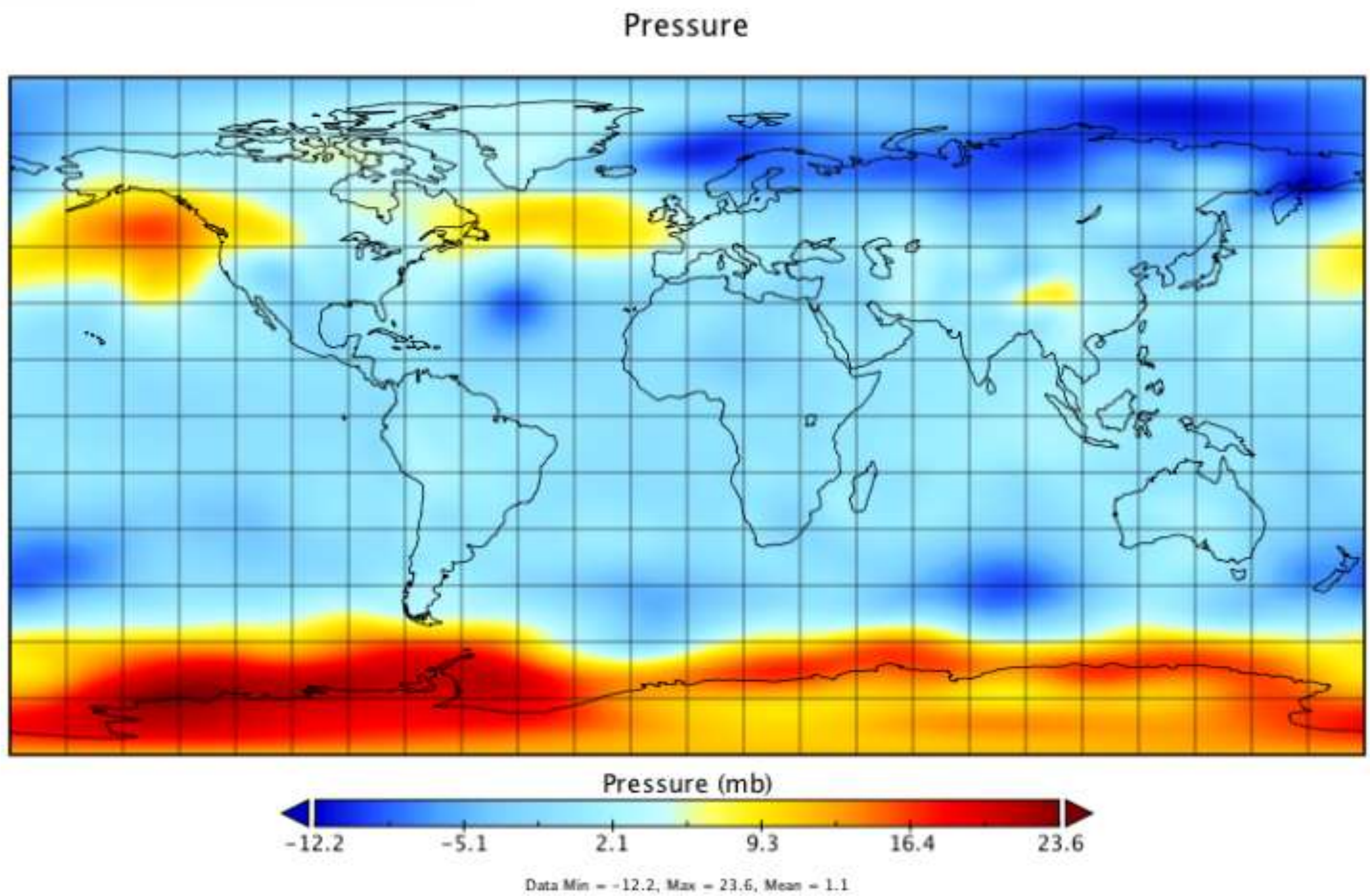
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **data.nc.** Change the name of the file to **SLPAnomaly.nc** by right-clicking on the dataset and selecting "rename".

Step 3. Open the **SLPAnomaly.nc** dataset in Panoply.

Step 4. In Panoply, go to the **SLPAnomaly.nc** dataset and click on the variable titled **"pressure"** and then click **"Create Plot"** in the top left corner as shown below:



When prompted, click **Create** again and you should see a map that looks like the following:



Step 5. Go to the **Scale** tab near the bottom of Panoply and make the following changes, as shown in the image below:

- Change the **Scale Range: Min to -8** and the **Max to 8.**
- Change the **Color Table** to **CB_PRGn.cpt**
- Change the **Divisions, Major** to **4**.

Step 6. Next, go to the **Contours** tab and make the following changes, as shown in the image below:

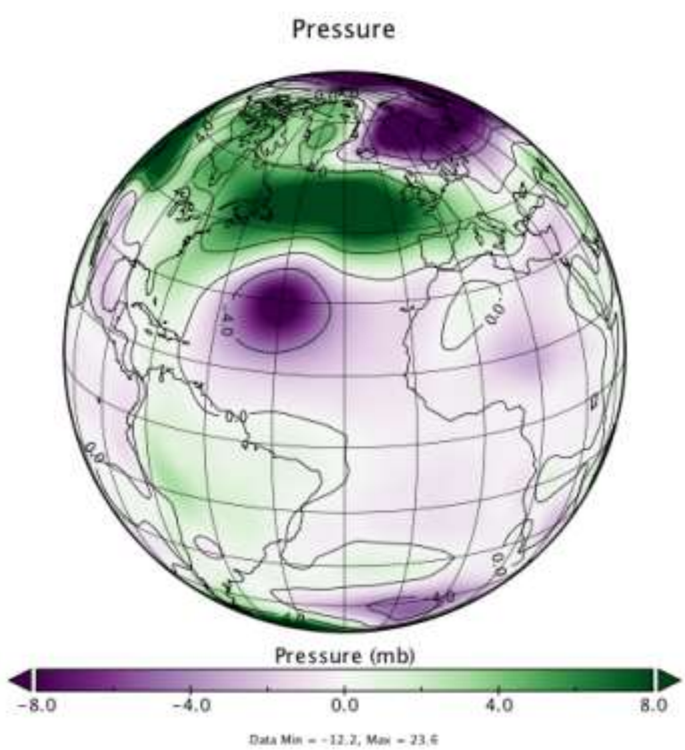
- Change the **Style** to **Solid**
- Check off the **box** for **Labels**
- Change the **Size** of the labels to **10**

Step 7. Go to the **Map** tab and make the following changes, as shown in the image below:

- Change the **Projection** to **Orthographic**.
- Change the **Center** on **Lon** to **-30˚E** and **Lat** to **20˚N.**

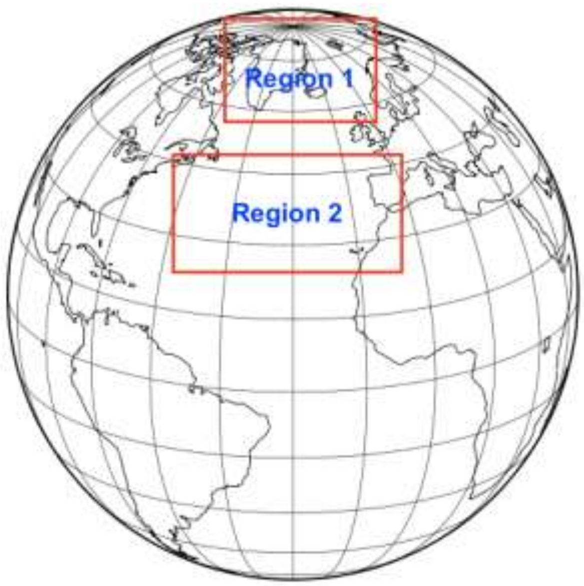
These changes result in a spherical map that is centered on the longitude -30˚E (30˚W) and latitude 20˚N so that the focus of the map is on the North Atlantic Ocean.

Step 8. You should now see a map that looks like the following:



The contour lines on the map represent lines of constant sea level pressure anomalies and accompany the color scale of the map.

Step 9. The Arctic Oscillation (AO) has two phases, positive AO & negative AO, and is influenced by the air pressure in two regions in the North Atlantic Ocean. Below is a map outlining the general regions in which air pressure can impact the AO.



Step 10. Go to the **Array(s)** tab near the bottom of Panoply and change the **Time** to **493** to represent sea level pressure anomalies during the month of January 1990 (1990-01-16), as shown in the image below.

During January 1990, the **AO** was in the **positive** phase.

Q1. Based on the locations of Region 1 (northern North Atlantic Ocean) and Region 2 (southern North Atlantic Ocean) shown in the image above from step #9, describe general the sea level pressure anomalies during January 1990 within each region.

Region 1: ____

Region 2: ____

Q2. The sea level pressure anomalies in the two regions of the North Atlantic Ocean during January 1990 are examples of typical sea level pressure anomalies in those regions during the positive phase of the Arctic Oscillation.

Based on this information, how do you think scientists are able to classify a **positive AO** event?

____

____

Step 11. Go to the **Array(s)** tab near the bottom of Panoply and change the **Time** to **734** to represent sea level pressure anomalies during the month of February 2010. During February 2010, the **AO** was in the **negative** phase.

Q3. Based on the locations of Region 1 (northern North Atlantic Ocean) and Region 2 (southern North Atlantic Ocean) shown in the image above from step #9, describe the general sea level pressure anomalies during February 2010 within each region.

Region 1: ____

Region 2: ____

Q4. The sea level pressure anomalies in the two regions of the North Atlantic Ocean during February 2010 are examples of typical sea level pressure anomalies in those regions during the negative phase of the Arctic Oscillation.

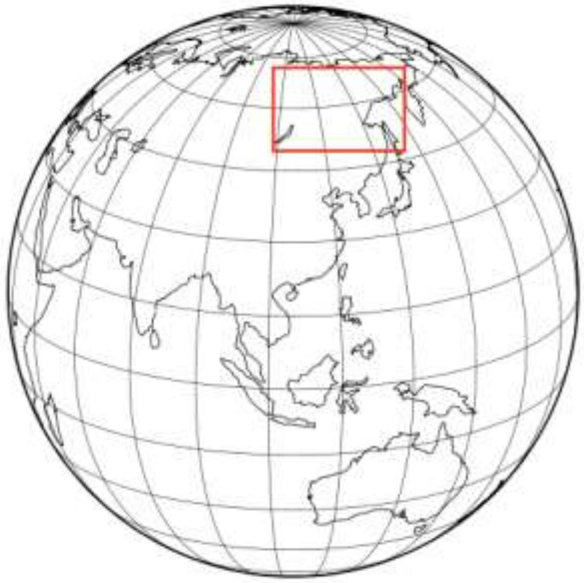
Based on this information, how do you think scientists are able to classify a **negative AO** event?

____

____

Step 12. Go back to the **Array(s)** tab and change the **Time** back to **493** to represent sea level pressure anomalies during the month of January 1990, a month in which the **AO** was in its **positive** phase.

Next, go to the **Map** tab and change the **Center on Lon** to **110˚E**. The map should now be centered on 110˚E longitude so the focus of the map is on eastern Russia, specifically eastern Siberia. The map below shows the region of interest.



Q5. In general, describe the sea level pressure anomalies in eastern Siberia during the **positive AO** event in **January 1990**. Use the image above from step #12 for regional guidance.

____

____

Step 13. Go to the **Array(s)** tab and change the **Time** back to **734** to represent sea level pressure anomalies during the month of February 2010, a month in which the **AO** was in its **negative** phase. Check to make sure the Lon is still centered on 110˚E longitude.

Q6. In general, describe the sea level pressure anomalies in eastern Siberia during the **negative AO** event in February 2010. Use the image above from step #12 for regional guidance.

____

____

Q7. Based on the sea level pressure anomalies in eastern Siberia in January 1990, what can you conclude about the change in air pressure in eastern Siberia during **positive phases of the Arctic Oscillation** (AO)?

____

____

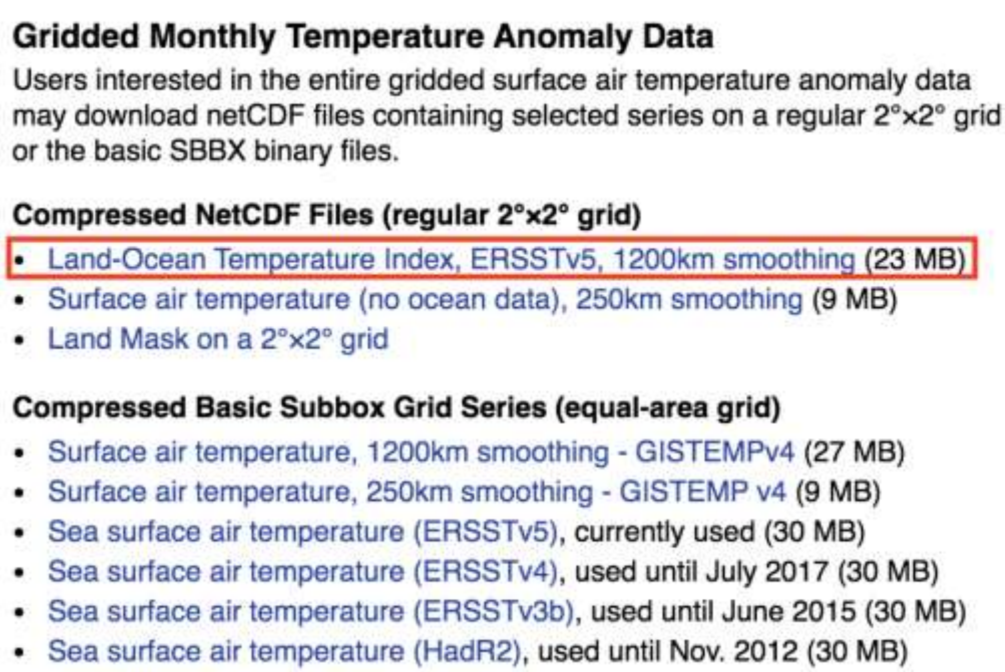
Q8. Based on the sea level pressure anomalies in eastern Siberia in February 2010, what can you conclude about the change in air pressure in eastern Siberia during **negative phases of the Arctic Oscillation** (AO)?

____

____

Step 14. Go to this link to access surface temperature anomaly data from NASA's GISTEMP. Scroll down towards the bottom of the page to a section titled **Gridded Monthly Temperature Anomaly Data**, and click on the link titled **Land-Ocean Temperature Index, ERSSTv5, 1200km smoothing** to download average monthly surface temperature anomaly data, as shown in the image below. The data is from January 1880 to June 2020*, which results in 1686 time slices, one for each month between January 1880 and June 2020.

*__Note__: At the time this activity was created, the data was updated as of June 2020. As more time passes, the last month and year of the dataset will change to a later time.



Gridded Monthly Temperature Anomaly Data

Users interested in the entire gridded surface air temperature anomaly data may download netCDF files containing selected series on a regular 2°×2° grid or the basic SBBX binary files.

Compressed NetCDF Files (regular 2°×2° grid)

- Land-Ocean Temperature Index, ERSSTv5, 1200km smoothing (23 MB)
- Surface air temperature (no ocean data), 250km smoothing (9 MB)
- Land Mask on a 2°×2° grid

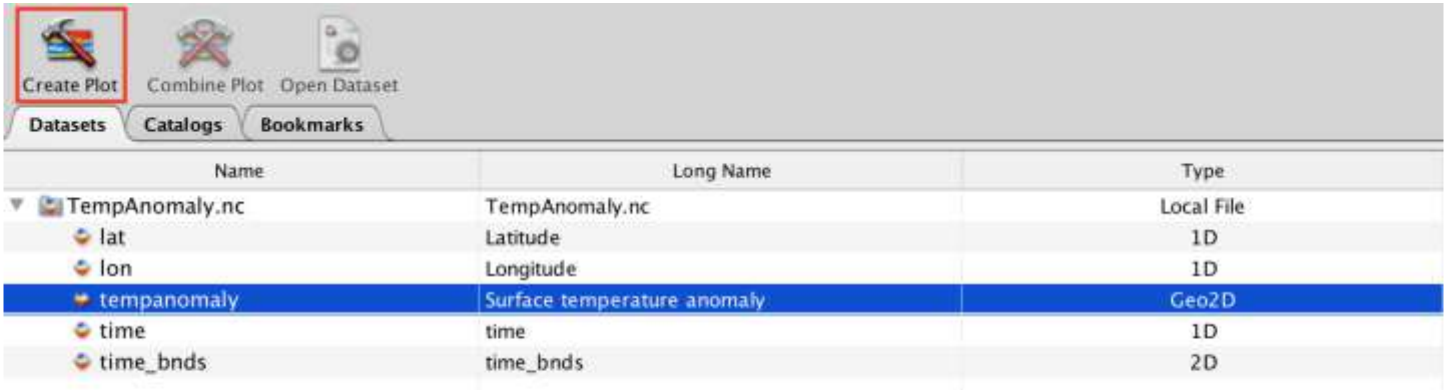
Compressed Basic Subbox Grid Series (equal-area grid)

- Surface air temperature, 1200km smoothing - GISTEMPv4 (27 MB)
- Surface air temperature, 250km smoothing - GISTEMP v4 (9 MB)
- Sea surface air temperature (ERSSTv5), currently used (30 MB)
- Sea surface air temperature (ERSSTv4), used until July 2017 (30 MB)
- Sea surface air temperature (ERSSTv3b), used until June 2015 (30 MB)
- Sea surface air temperature (HadR2), used until Nov. 2012 (30 MB)

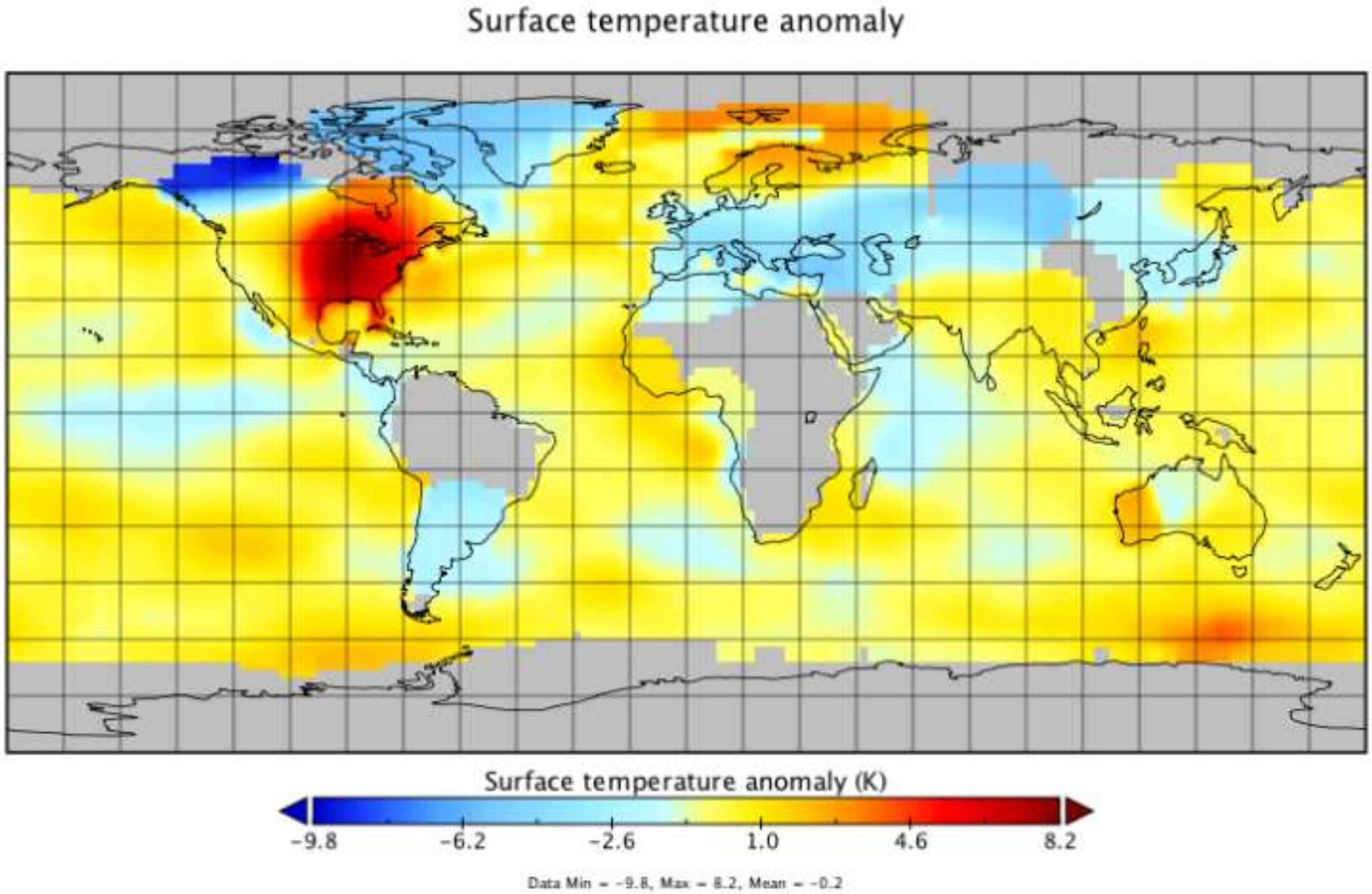
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **gistemp1200_GHCNv4_ERSSTv5.nc.** Change the name of the file to **TempAnomaly.nc** by right-clicking on the dataset and selecting "rename".

Step 15. Open the **TempAnomaly.nc** dataset in Panoply.

Step 16. In Panoply, go to the **TempAnomaly.nc** dataset and click on the variable titled **"tempanomaly"** and then click **"Create Plot"** in the top left corner as shown below:



When prompted, click **Create** again and you should see a map that looks like the following:



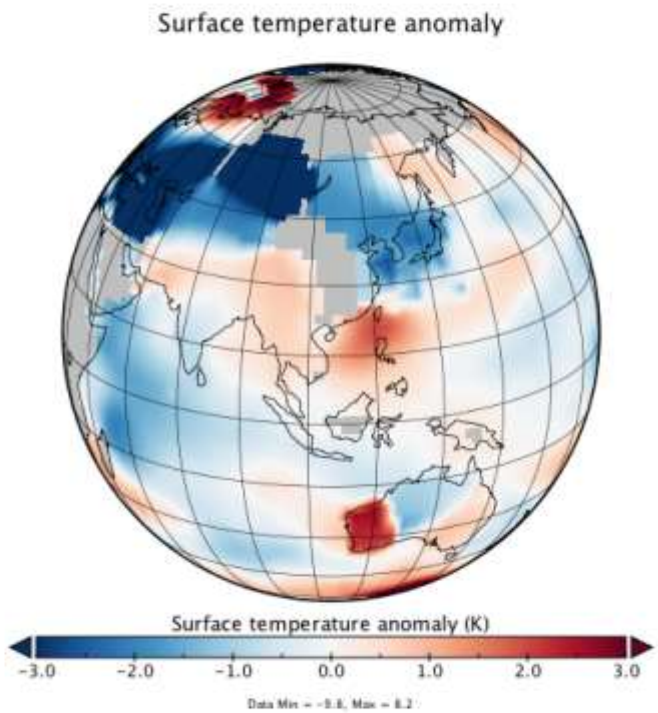
Step 17. Go to the Scale tab and make the following changes, as shown in the image below:

- Change the **Scale Range: Min to -3** and the **Max to 3.**
- Change the **Divisions, Major** to **6**.
- Change the **Color Table** to **CB_RdBu.cpt**
- Check the box for **Reverse colors**

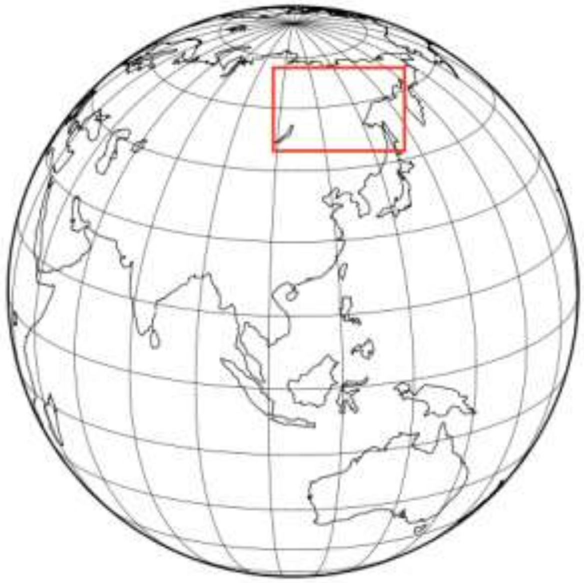
Step 18. Go to the **Map** tab and make the following changes, as shown in the image below:

- Change the **Projection** to **Orthographic**.
- Change the **Center** on **Lon** to **110˚E** and **Lat** to **20˚N.**

Step 19. You should now see a map that looks like the following:



Step 20. Go to the **Array(s)** tab near the bottom of Panoply. Starting at **Time 1321,** slowly change the **Time** to **1322**, then **1323**, and **1324** to display the surface temperature anomalies from January 1990 to April 1990. During these months the **Arctic Oscillation** was in its **positive** phase. Focus specifically on the surface temperature anomalies in the eastern Siberia region outlined in the map below, which is the same as the one provided above in step #12.



Q9. In general, describe the overall surface temperature anomalies in eastern Siberia from January 1990 to April 1990, a time when the Arctic Oscillation was in its positive phase.

____

____

Step 21. Go to the **Array(s)** tab near the bottom of Panoply. Starting at **Time 1560**, slowly change the **Time** to **1561**, then **1562**, then **1563,** and **1564** to display the surface temperature anomalies from December 2009 to April 2010. During these months the **Arctic Oscillation** was in its **negative** phase. Focus specifically on the surface temperature anomalies in the eastern Siberia region.

Q10. In general, describe the overall surface temperature anomalies in eastern Siberia from December 2009 to April 2010, a time when the Arctic Oscillation was in its negative phase.

____

____

Q11. Based on the surface temperature anomalies in eastern Siberia from January 1990 to April 1990, what can you conclude about the change in surface temperature in eastern Siberia during **positive phases of the Arctic Oscillation** (AO)?

____

____

Q12. Based on the sea level pressure anomalies in eastern Siberia from December 2009 to April 2010, what can you conclude about the change in surface temperature in eastern Siberia during **negative phases of the Arctic Oscillation** (AO)?

____

____

Q13. The Arctic Oscillation (AO) is another example of a teleconnection. The AO can be measured by the strength of low-pressure and high-pressure systems within the northern Atlantic Ocean. Based on what you learned about the AO and also El Niño, define the meaning of “teleconnection”.

____

____

____

____

EXPLAIN

Step 1. Read the information provided in the excerpt below from UCAR Center for Science Education to learn about the meaning of the term "teleconnections". The excerpt can also be accessed from this UCAR website about teleconnections.

Changes in the atmosphere in one place can affect weather over 1000 miles away. Scientists are trying to sort out how this works so that they can better understand and predict weather patterns worldwide. They call these patterns teleconnections.

Teleconnection patterns are caused by changes in the way air moves around the atmosphere. The changes may last from a few weeks to many months. Teleconnection patterns are natural. However, they may be changed as Earth's climate warms.

Q1. Based on the information given above, define teleconnection.

____

____

Q2. An El Niño event characterized by higher than normal sea surface temperature anomalies in the eastern equatorial Pacific Ocean can increase temperatures along the northwest coast of North America.

Explain why El Niño events are considered to have teleconnections.

____

____

Q3. The positive phase of the Arctic Oscillation is characterized by lower than normal sea level pressure in the northern region of the North Atlantic Ocean (near Greenland) and higher than normal sea level pressure anomalies in the southern region of the North Atlantic Ocean. A positive AO event can lead to higher than normal surface temperature in eastern Siberia.

Explain why the Arctic Oscillation is considered to be a teleconnection.

____

____

Step 2. Go to this link to access information from the National Snow & Ice Data Center about the Arctic Oscillation.

Step 3. Before you read the text, read Q4 through Q11 below to learn the content you should focus on. Then, read the entire text.

Once you read the text, answer Q4 through Q11.

Q4. The beginning of the text references how the Arctic Oscillation (AO) has influenced winter weather patterns in the United States. How does the **negative mode** (phase) of the AO influence weather in the United States during the winter?

____

____

Q5. The beginning of the text references how the Arctic Oscillation (AO) has influenced winter weather patterns in the United States. How does the **positive mode** (phase) of the AO influence weather in the United States during the winter?

____

____

Q6. The Arctic Oscillation is based on pressure patterns in which two general regions?

(1) ____

(2) ____

Q7. In general, the change in mode of the Arctic Oscillation influences a change in what?

____

____

Q8. Describe the general air pressure patterns in both regions identified in Q6 during the **negative** mode of the AO.

____

____

Q9. Describe the general air pressure patterns in both regions identified in Q6 during the **positive** mode of the AO.

____

____

Q10. During the **positive** mode of the AO, explain why storms shift further north in the winter, leaving locations in the mid-latitudes drier and warmer than normal.

____

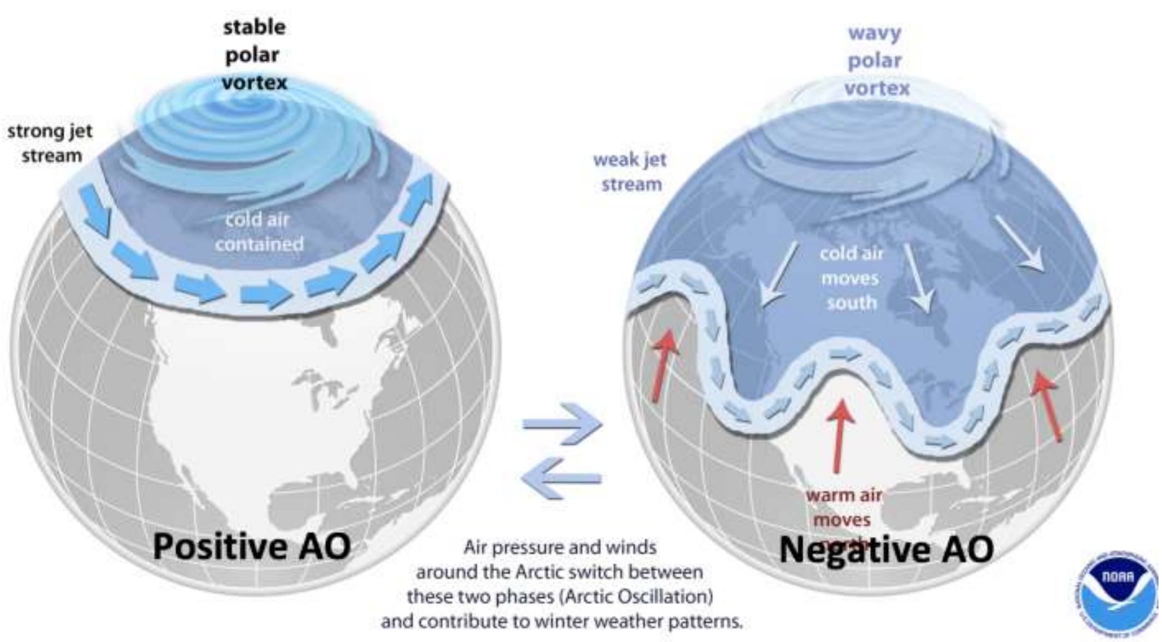
____

Q11. During the **negative** mode of the AO, explain why there are more snowstorms in the winter in the mid-latitudes.

____

____

Step 4. The image below from NOAA shows the changes to atmospheric circulation through the jet stream during the positive AO (left) and negative AO (right). The jet stream is a band of strong winds in the upper atmosphere that travels from west to east and acts as a boundary between cold air to the north and warmer air to the south.



Q12. Based on the image above, describe what happens to the cold polar air from the polar vortex when the AO is both positive and negative.

+ AO: ____

____

- AO: ____

____

Q13. There are two sets of blank maps after Q17, one set is titled Positive AO and the other set is titled Negative AO. Within each set of maps, there is one centered on the North Atlantic Ocean, and the other is centered on Siberia. Use the symbols below to complete the following task:

- **Positive AO**: Label the map centered over the North Atlantic Ocean based on the air pressure trends in the mid-latitudes of the North Atlantic Ocean and the Arctic. The symbols need to be drawn in the correct locations on the map.

- **Negative AO**: Label the map centered over the North Atlantic Ocean based on the air pressure trends in the mid-latitudes of the North Atlantic Ocean and the Arctic. The symbols need to be drawn in the correct locations on the map.

Symbols:

H = Higher than normal pressure   **L** = Lower than normal pressure

Q14. From January 2020 to June 2020, Siberia experienced warmer than normal temperatures, leading to drier conditions conducive to wildfires. According to an article from the NASA Earth Observatory titled Heat and Fire scorches Siberia, a persistent high-pressure system is responsible for the positive temperature anomalies and dry conditions. From January to April 2020, the AO was in its positive mode.

- **Positive AO**: Use the symbols from Q13 to label the map centered over Siberia with the correct air pressure trend over Siberia.

- **Negative AO**: Use the symbols from Q13 to label the map centered over Siberia with the correct air pressure trend over Siberia.

Q15. Based on what you have learned about the Arctic Oscillation thus far, complete the following tasks:

- On both maps for each phase of the AO (four maps total), gently shade the Arctic Circle light blue to represent the location of cold Arctic air from the polar vortex. The shading should be the same on all maps.

Q16. There are two tasks below.

- On both Positive AO maps, draw arrows with a purple colored pencil to show the strong movement of a northern jet stream that confines the cold air from the polar vortex within the Arctic.

- On both Negative AO maps, draw arrows with a purple colored pencil to show the southward movement of the cold air from the polar vortex due to the southward shift of the jet stream.

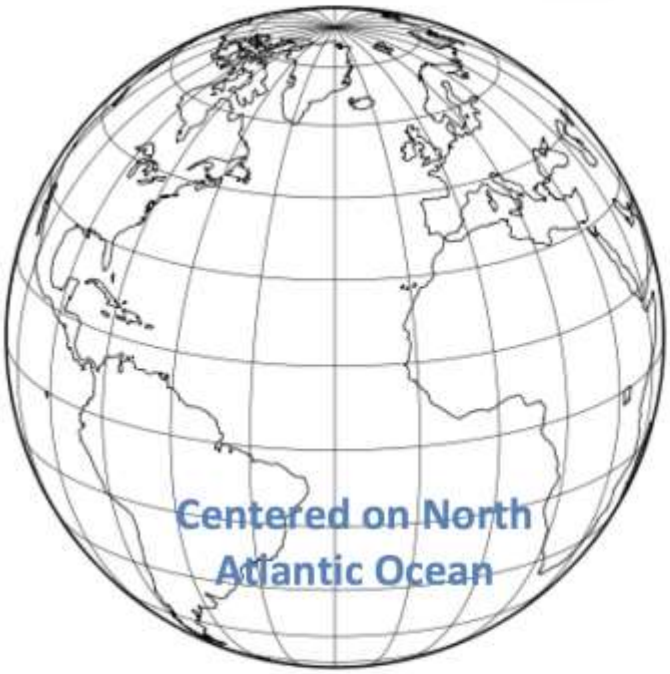
Q17. Complete the tasks below using only the map centered over Siberia.

- **Positive AO**: Gently shade eastern Siberia with a dark blue or red colored pencil to represent whether temperature is lower than normal or higher than normal, respectively.

- **Negative AO**: Gently shade eastern Siberia with a dark blue or red colored pencil to represent whether temperature is lower than normal or higher than normal, respectively.

Positive AO

Negative AO



Q18. Based on what you have learned about the Arctic Oscillation thus far, explain how the **positive phase** of the AO influences the pressure and temperature over eastern Siberia. Your answer should include a description of how temperature and pressure change, and why the change occurs.

____

____

____

____

Q19. Based on what you have learned about the Arctic Oscillation thus far, explain how the **negative** phase of the AO influences the pressure and temperature over eastern Siberia. Your answer should include a description of how temperature and pressure change, and why the change occurs.

____

____

____

____

Q20. From January 2020 to June 2020, Siberia has been experiencing warmer than normal temperatures, leading to drier conditions conducive to wildfires. More information about this can be found at this article from the NASA Earth Observatory titled Heat and Fire scorches Siberia.

Explain how the Arctic Oscillation played a role in the heat wave that resulted in environmental conditions conducive to wildfires. Your answer should include the phase of the AO, and its impact on pressure and temperature in Siberia.

____

____

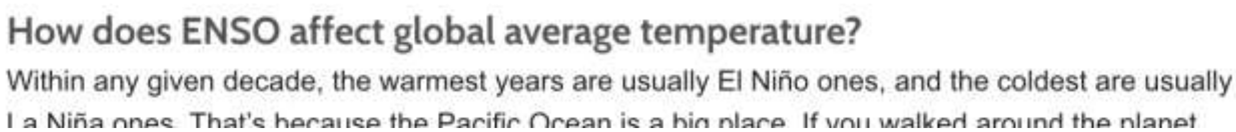
____

____

ELABORATE

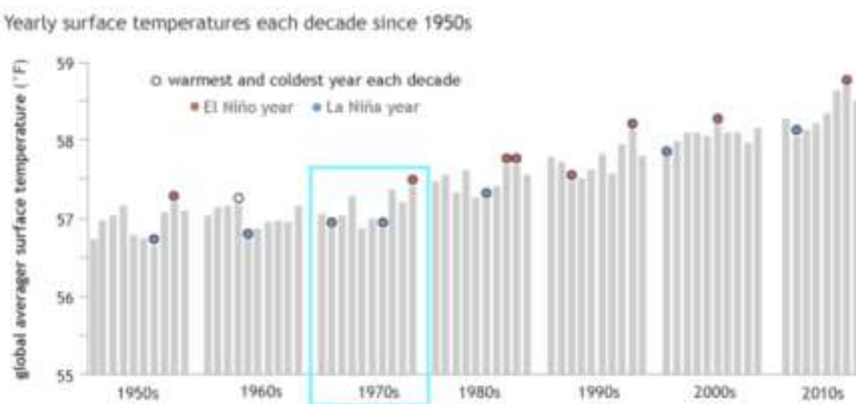
Step 1. Atmospheric teleconnections like the Arctic Oscillation (AO) and El Niño Southern Oscillation (ENSO) can have a large impact on both local and global climate. In the EXPLORE and EXPLAIN activities you had the opportunity to learn how the Arctic Oscillation can impact local climate through the heat waves and wildfires in Siberia. In this ELABORATE activity, you will investigate how ENSO can impact global temperatures.

Go to this link from NOAA to read how the phase of ENSO has impacted average global temperature since the 1950s. Scroll down to the section titled **How does ENSO affect global temperature**, as shown in the image below, and read the text in that section.


How does ENSO affect global average temperature?

Within any given decade, the warmest years are usually El Niño ones, and the coldest are usually La Niña ones. That's because the Pacific Ocean is a big place. If you walked around the planet

Step 2. The graph titled **Yearly surface temperature each decade since the 1950s** shows the average global temperature for each year from 1950 to 2017. Each year is grouped into a decade representing the 1950s, 1960s, 1970s, 1980s, 1990s, 2000s, or 2010s. An example of the years grouped in the 1970s decade is shown below.



In each decade, the highest and lowest average global temperature is marked with a circle. Each circle is colored to represent the El Niño, La Niña, or Neutral phrase of ENSO. The color codes are:

- White circle = Neutral ENSO
- Red circle = El Niño
- Blue circle = La Niña

Note: Some decades have more than one circle for highest and lowest temperature due to repeats.

Q1. How many times was the **Neutral phase of ENSO** occurring when the **highest** temperature was recorded in each decade?

____

Q2. How many times was the **El Niño phase of ENSO** occurring when the **highest** temperature was recorded in each decade?

____

Q3. How many times was the **La Niña phase of ENSO** occurring when the **highest** temperature was recorded in each decade?

____

Q4. Based on your answers to Q1 to Q3 and the data from the **Yearly surface temperature each decade since the 1950s** graph, what conclusion can you make about the phase of ENSO and global average temperature?

____

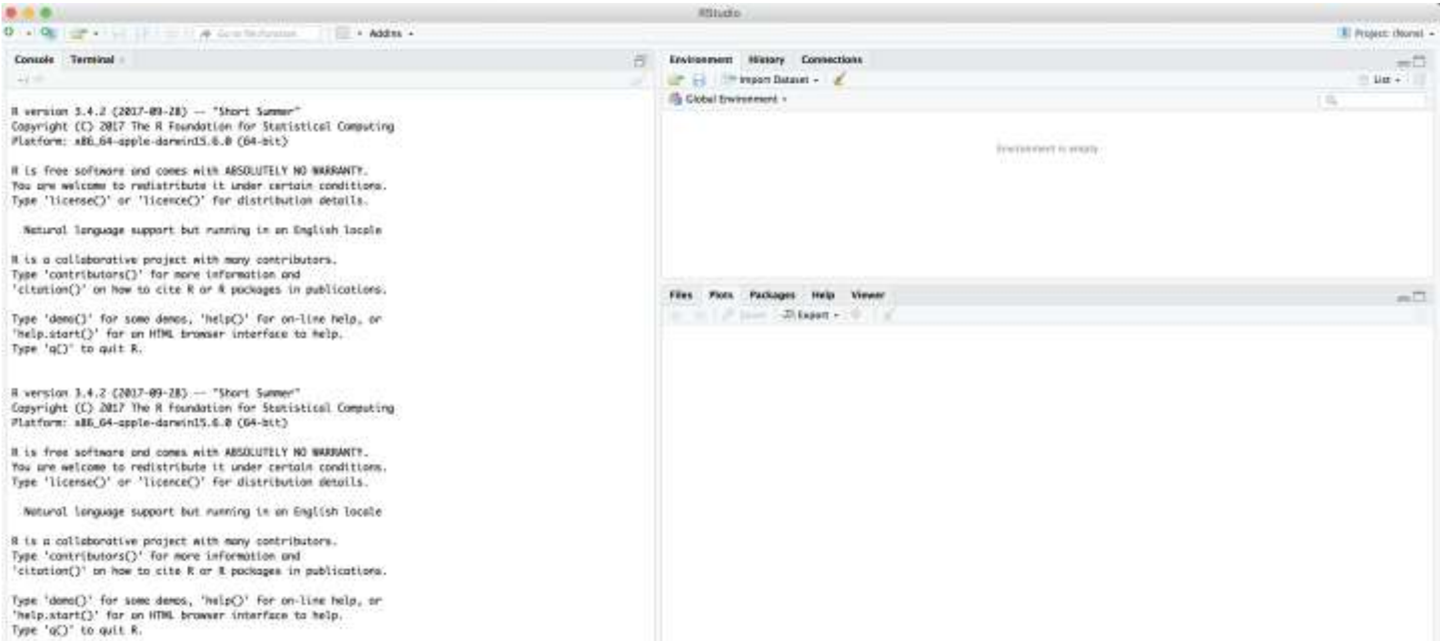
____

Step 3. NASA GISS scientists Nathan Lenssen, Gavin Schmidt, James Jansen, Matthew Menne, Avraham Persin, Reto Ruedy, and Daniel Zyss have been exploring how the December/January phase of ENSO can be used to predict average global temperature for the upcoming year. For example, the December 2017/January 2018 ENSO phase can be used to predict the average global temperature for 2018.

To do this, the NASA GISS Scientists created a code using the R programming language that utilizes global temperature anomaly data from NASA's GISTEMP and the Multivariate El Niño Southern Oscillation 2 (MEI2) Index.

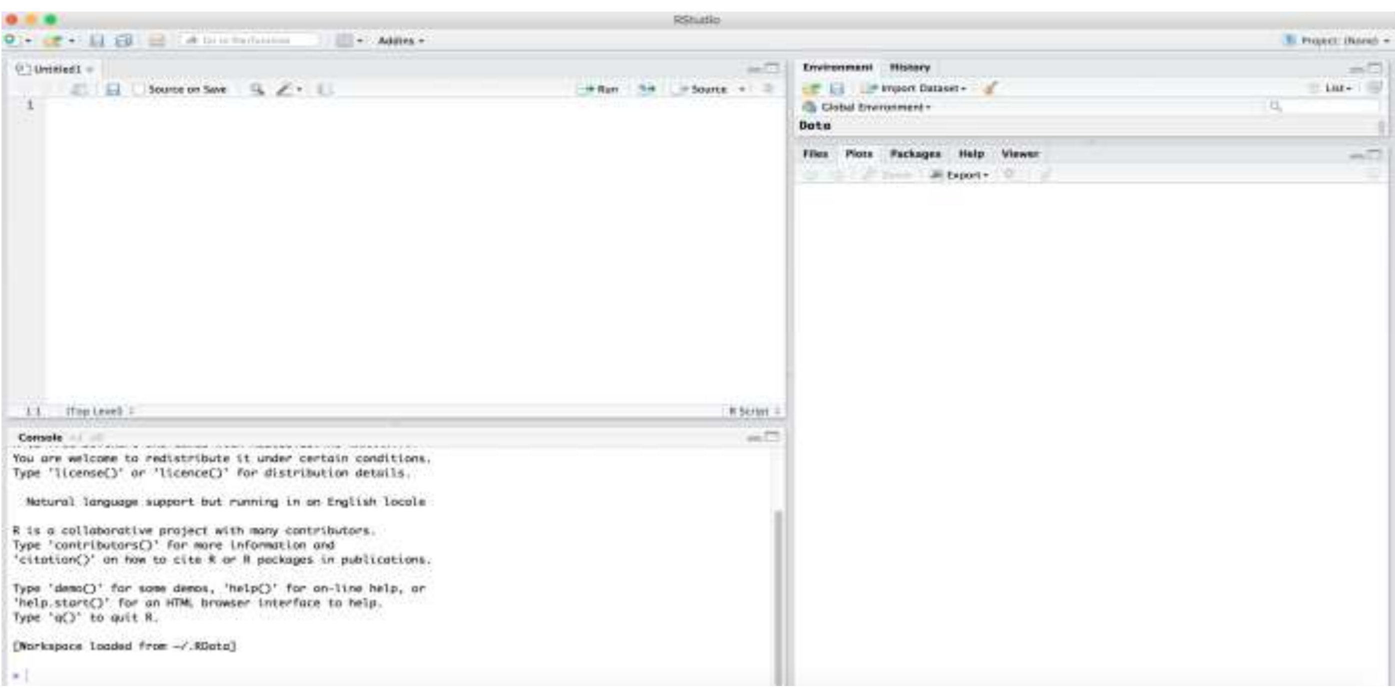
Step 4. Ensure that Rstudio is installed on your computer. If RStudio is not downloaded on your computer, please complete the download instructions provided by your teacher.

Step 5. Open RStudio and you will see a screen that looks like this.



Step 6. At the top left of Rstudio, click on **File**, then **New File,** and then click **R Script**.

Step 7. You should now see the following on your screen in the image below. The image shows a blank script in the top left of the program, and now the Console is on the bottom left of the program.



Step 8. The ***top left panel*** of RStudio contains the **R Script** that will be used to write code with the R programming language. Once a script is created, a user can run the entire script or run the script line by line or section by section.

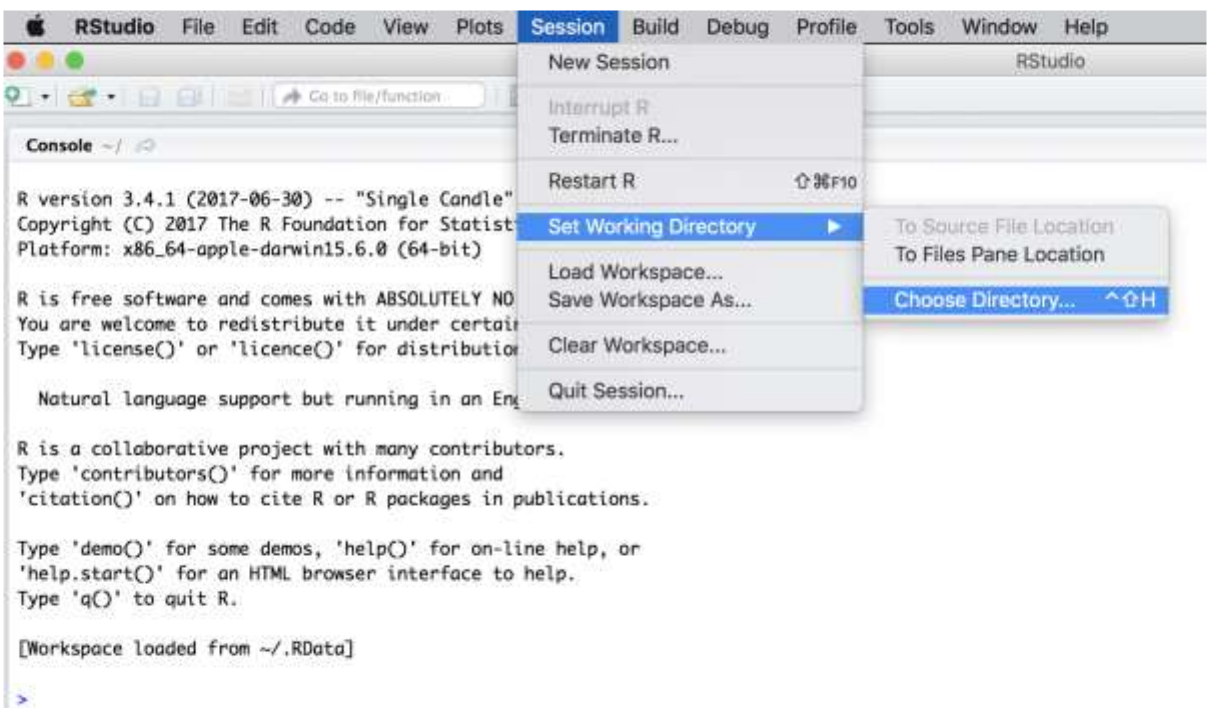
The ***bottom left panel*** of RStudio contains the **Console** which displays the lines of code that the user selects to run. Users can also type commands and perform calculations directly in the **Console** for a quick answer rather than writing a script and waiting for an answer after running the script.

The ***top right side*** of RStudio contains an **Environment tab** which lists all of the datasets that have been loaded into RStudio. There is also a **History tab** that contains the history of everything that was typed into the **Console**.

The ***bottom right side*** of RStudio contains a **Plot tab** that allows users to look at any plots that are created. There is a **Packages tab** that allows users to download packages that are needed for specific R tasks, and there is a **Help tab** that allows users to search how to use specific commands in R.

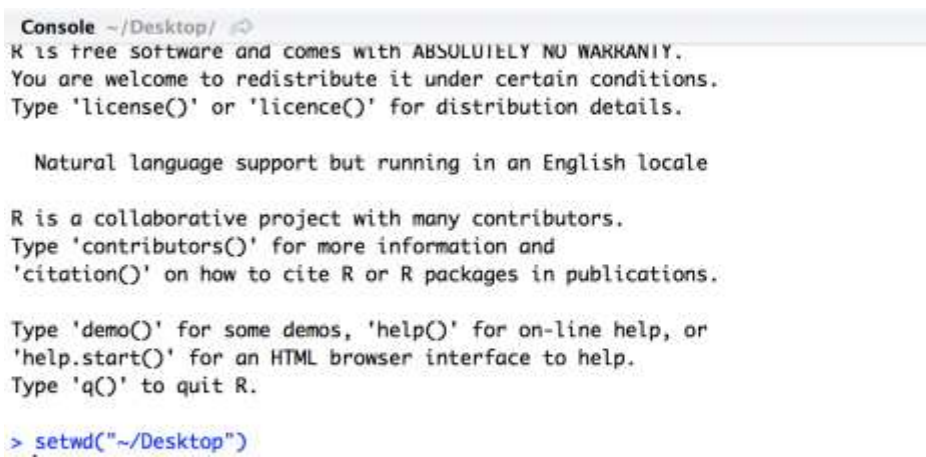
Step 9. We will begin by setting our **Working Directory** in Rstudio. A **Working Directory** is the location/folder on your computer where you want your work to be stored. A **Working Directory** could be the Documents folder of your computer, the Downloads folder, Desktop folder, or any other folder. For this activity, we will all be using the **Desktop** folder as our **Working Directory**.

To set your Working Directory in RStudio, go to **Session** at the top, then click on **Set Working Directory**, and then click on **Choose Directory**, as shown in the image below.



A window will pop-up depending on your computer, which could be similar to the image below. Click on the **Desktop** folder and then click **Open**.

The **Working Directory** should now be set to the Desktop folder, and the **Console** should look like the following:



The command **setwd("~/Desktop")** in the blue font in the Console is a result of setting your working directory. The top left of the Console should now show that the Desktop folder is the **Working Directory**, as shown in the image below:

Step 10. Make sure you have the **GISTEMP_Download.R** script provided by your teacher saved in your Desktop folder.

Step 11. Make sure you have the **MEI2_Download.R** script provided by your teacher saved in your Desktop folder.

Step 12. When RStudio is first downloaded, it comes with a default set of commands and libraries. To complete this activity, users need to install the **sm and gdata** libraries. These libraries are needed for RStudio to do statistical calculations within the code.

Go to the **Console** and ***type*** **install.packages("sm")** and then press enter. The library package will download in the **Console**.

Then, go to the **Console** and ***type*** **install.packages("gdata")** and then press enter. The library package will download in the **Console**.

Step 13. Once a library is downloaded, it does not need to be downloaded again. However, it does need to be referenced at the top of every R Script that uses the **sm and gdata libraries**. It is always a great idea to reference the libraries needed in each script at the top of the code.

Open another blank RScript and save it as **Temperature_Predictions.R**

On line #1 of the code type **library(sm)**

On line #2 of the code type **library(gdata)**

Library is a command in line #1 and there, you are referencing the **sm library** with the library command. On line #2, you are referencing the **gdata library**.

Step 14. Within the code statements can be written that explain the function of the steps that follow. The statements need to be "commented out", which means the writing will not be part of the code when the code is later running.

In the R language, the symbol "#" needs to be placed in the beginning of each line of the code that is meant to be commented out. For example:

#This statement is written to teach students how to comment out a line in a R code.

Later when the code you write is running, R Studio will not include any line that is commented out in the calculations or procedures you are performing in your code.

Step 15. On line #4 in the RScript, write the following comment:
#Run the GISTEMP_Download.R and MEI2_Download.R scripts to download the gistemp_v4_mon.lp and MEI2.txt datasets

Step 16. We will now write statements that will run the **GISTEMP_Download.R** and **MEI2_Download.R** scripts you downloaded from your teacher earlier.

First will be the **GISTEMP_Download.R** file. To run this script, we need to use a command called **source**. The only argument we will use in the **source** command is **file**, which is the file name of **GISTEMP_Download.R.** Since this file should already be in the Desktop folder of your computer, which is your working directory, you do not need to provide the entire file pathway.

On line #5 of the script, write the following:

source("GISTEMP_Download.R")

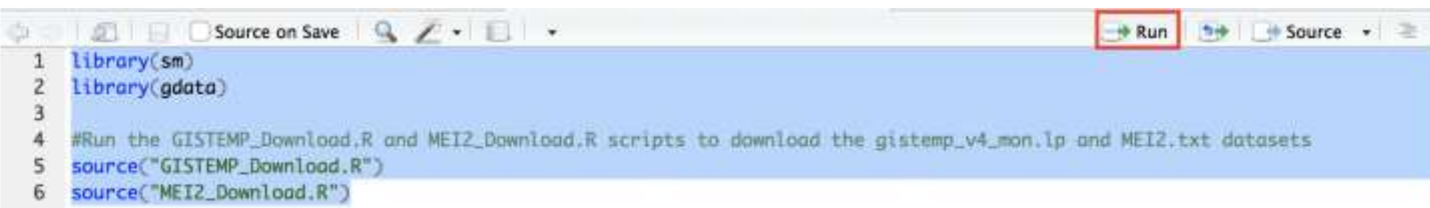
On line #6 of the script, write the following to source the **MEI2_Download.R** script:

source("MEI2_Download.R")

Step 17. Your RScript should now look similar to the following:

```
1  library(sm)
2  library(gdata)
3
4  #Run the GISTEMP_Download.R and MEI2_Download.R scripts to download the gistemp_v4_mon.lp and MEI2.txt datasets
5  source("GISTEMP_Download.R")
6  source("MEI2_Download.R")
```

Step 18. Highlight and run lines 1 through 6 in the code, as shown in the image below.



Check the Console to see if there are any error messages. If there are no error messages, your Console should show verification that the data was downloaded.

If there are error statements in the **Console**, it is most likely due to an incorrect file pathway in the source commands from lines #5 and #6. If you are unsure about your error statement, it can be helpful to copy and paste the error message into Google to learn more about your error.

Step 19. Now that the data we need is loaded into RStudio, we need to source the RScript that contains all of the calculations. These calculations lead to annual global temperature anomalies and statistical analyses between the temperature anomaly and MEI2 data. The source RScript also creates plots for further analysis.

The source RScript will be provided to you by your teacher and is titled **Temperature_Predictions_Source.R**

Once you receive the **Temperature_Predictions_Source.R** file, be sure to save it to your **Desktop** folder. **Do not change the name of the file!**

Step 20. On line #8 of the code, write the following commented statement:
#Source the Temperature_Predictions_Source.R script. This RScript contains the code that performs all of the calculations and makes plots for further analysis.

Step 21. To source a RScript, we need to use the **source** command. The only argument we will use in the **source** command is **file**, which is the pathway to the **Temperature_Predictions_Source.R**

On line #9 of the code, write the **source** command with your file pathway to **Temperature_Predictions_Source.R** in parentheses.

An example of line #9 is shown below:

source("Temperature_Predictions_Source.R")

Step 22. Highlight and run line #9 of the code to execute the source **Temperature_Predictions_Source.R** script and check the **Console** to ensure there are no error statements. If there are no errors, your **Console** will look similar to the image below:

```
> source("Temperature_Predictions_Source.R")
[1] "The plot may be saved to a pdf file by either"
[1] "   changing the above line to :"
[1] "                              savepdf<-1"
[1] "Then re-running this script"
[1] "Or from your computer's command line::"
[1] "          Rscript Temperature_Predictions_Source.R 1"
[1] "Previous max(es) ( 2016 ): 1.02" "Previous max(es) ( 2020 ): 1.02"
[1] "2021 prediction based on YTD vs. Annual average regression 0.71 +/- 0.25 °C"
[1] "2021  prediction (based on ENSO in Dec/Jan): 1.01 +/- 0.22 °C"
[1] "2022  prediction (based on projected ENSO in Dec/Jan): 1.18 +/- 0.23 °C"
```

The last two predictions are of interest in this activity. These predictions are as of the current year 2021 and will be different as time goes on.

If there are errors in the Console, it is likely due to the location of the **Temperature_Predictions_Source.R** file. Please make sure the **Temperature_Predictions_Source.R** file is in the Desktop folder of your computer, and that the working directory for RStudio is set to Desktop. If you are unsure about your error statement, it can be helpful to copy and paste the error message into Google to learn more about your error.

Step 23. Before we continue, let's recap the goal of **Temperature_Predictions.R**.

The goal of the script is to use the December-January (DJ) MEI2 Index data to predict the average surface temperature anomaly for the upcoming year.

The last two lines of the **Console** shows two predictions that were calculated after running line #9 of the code. A description of both predictions is provided below:

- The first prediction is of the current year's average annual surface temperature anomaly based on the previous December-January (DJ) ENSO value from the MEI2 index. There is evidence that suggests the ENSO-DJ value relates to the upcoming average annual surface temperature anomaly.
    - For example, the December 2019/January 2020 ENSO value can help predict the 2020 average surface temperature anomaly.

- The second prediction is of the next year's average annual surface temperature anomaly based on the projected ENSO-DJ value.
    - For example, if the year is 2020, then the projected December 2020/January 2021 ENSO value is used to predict the average surface temperature anomaly for 2021.

Q5. The Console shows how the ENSO-DJ values can predict surface temperature anomalies for the current year and the next year. Fill in the blank spaces below with the year and the predicted values based on the information in the Console. (**Note:** The information in your Console will be different from the example above since the data is continuously updating).

- Current year ____________ prediction (based on ENSO-DJ): ________ +/- ________ **˚C**

- Next Year ____________ prediction (based on projected ENSO-DJ): ________ +/- ________ **˚C**

Q6. The **+/-** symbol followed by a number in the prediction means that the predicted value can be within a specified range.

For example, if the prediction was 2.11 +/- 0.5˚C, this means that the predicted value is likely to be somewhere between **1.61˚C** (the result from 2.11˚C – 0.5˚C) and **2.61˚C** (the result from 2.11˚C + 0.5˚C).

Using the example above as a guide, for each of the predictions provide the range of predicted values.

- Current year ____________ prediction range (based on ENSO-DJ): ______________________________

- Next Year ____________ prediction range (based on projected ENSO-DJ): ________________________

Step 24. A plot should have also appeared in the lower right window of RStudio. Answer the following questions based on the predictions in the Console and the information in the plot.

Q7. Click on **Export** in the Plot window and choose **Copy to Clipboard**, as shown in the image below.

A new window will pop-up. Choose **Copy Plot** near the bottom right of the window. This will make a copy of your plot that can then be pasted into a document. Paste a copy of your plot in the blank space below.

Q8. Based on the plot, describe the overall trend in annual average surface temperature anomalies from 1980 to present.

____

____

Q9. The plot shows the points representing the current year's and next year's surface temperature anomaly based on their previous ENSO-DJ index values. Based on the surface temperature anomaly values, during which year do you think the ENSO-DJ index was greater? Then, explain your answer.

Year: _____________

Explanation: ____

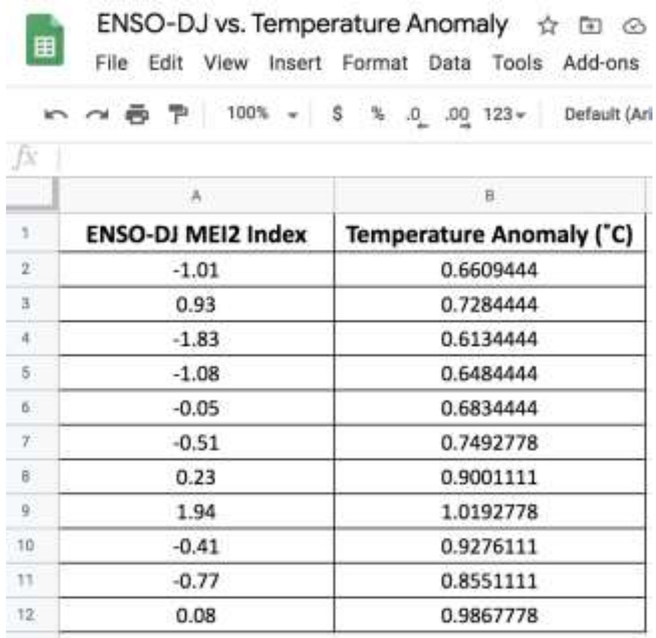
____

Step 25. The data table below contains the ENSO-DJ MEI2 Index and the average surface temperature anomaly from 2009 – 2019.

Year	ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
2009	-1.01	0.6609444
2010	0.93	0.7284444
2011	-1.83	0.6134444
2012	-1.08	0.6484444
2013	-0.05	0.6834444
2014	-0.51	0.7492778
2015	0.23	0.9001111
2016	1.94	1.0192778
2017	-0.41	0.9276111
2018	-0.77	0.8551111

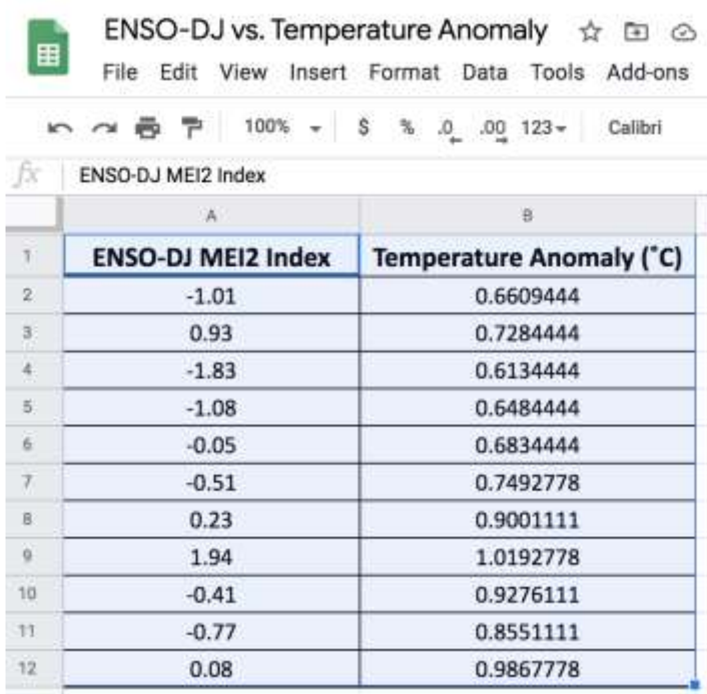
2019	0.08	0.9867778

Copy and paste the **ENSO-DJ MEI2 Index** and **Temperature Anomaly** columns of the data table above into the first cell in a blank **Google Sheets** document, as shown in the image below.



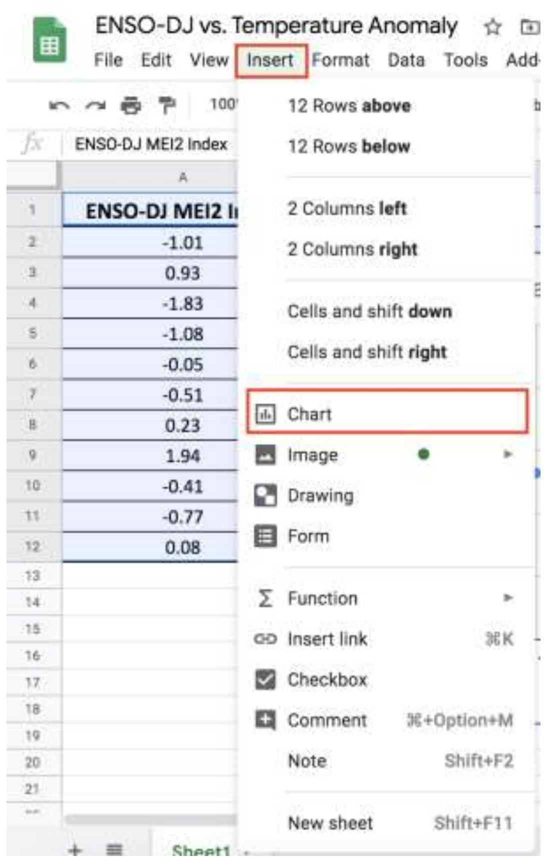
ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
-1.01	0.6609444
0.93	0.7284444
-1.83	0.6134444
-1.08	0.6484444
-0.05	0.6834444
-0.51	0.7492778
0.23	0.9001111
1.94	1.0192778
-0.41	0.9276111
-0.77	0.8551111
0.08	0.9867778

Step 26. Click on the first cell and drag to highlight all values as shown below.



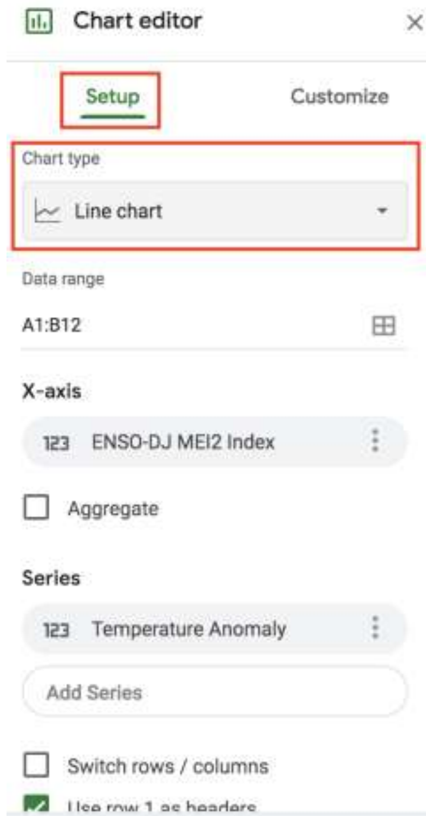
ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
-1.01	0.6609444
0.93	0.7284444
-1.83	0.6134444
-1.08	0.6484444
-0.05	0.6834444
-0.51	0.7492778
0.23	0.9001111
1.94	1.0192778
-0.41	0.9276111
-0.77	0.8551111
0.08	0.9867778

Then, click **Insert** near the top, and then click on **Chart**, as shown in the image below.



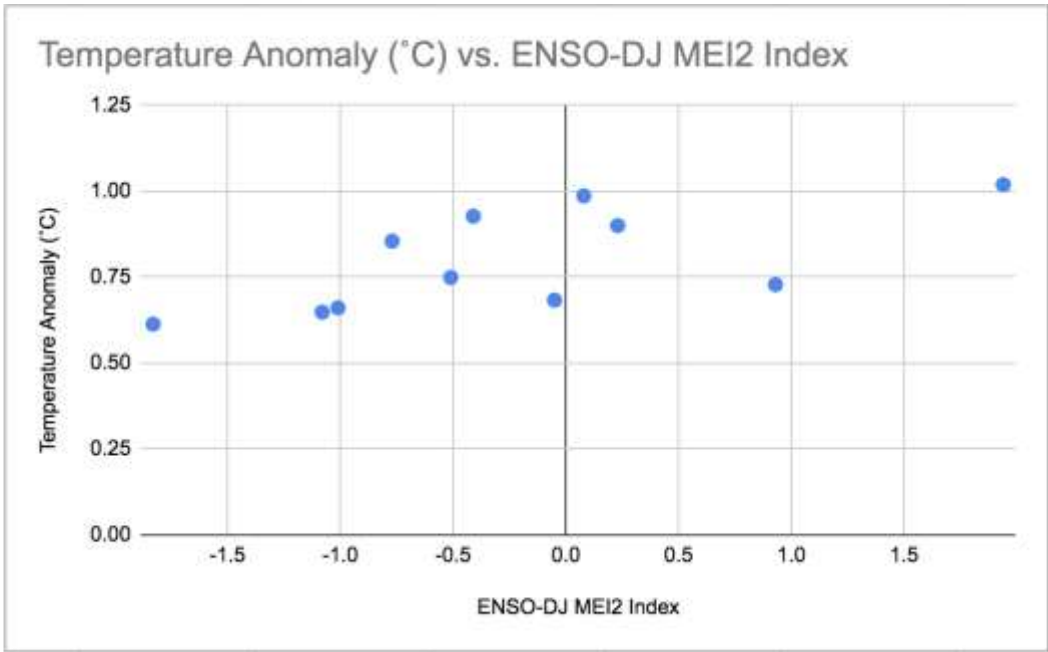
A chart will then be created, but we want to ensure the chart is a scatter plot. To do this, we need to use the Chart Editor, which should have appeared on the right side of Google Sheets.

At the top of the Chart Editor, click on **Setup**, and then **Chart type**, as shown in the image below.

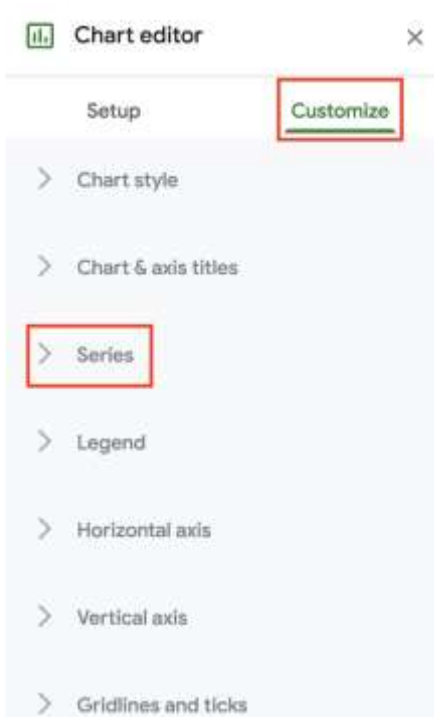


Look for the option that shows a scatter plot with all blue dots, as shown in the image below.

Your graph should now look like the following:



Step 27. On the top of the Chart Editor, click on Customize. Then, choose Series, as shown below.



Next, scroll down and check the box for Trendline.

Q10. Copy and paste the scatter plot you created into the blank space below.

Q11. Based on the scatter plot created in Google Sheets, what is the general relationship between the ENSO-DJ MEI2 Index and the temperature anomaly?

____

____

Q12. Go back to the plot created in RStudio. Based on the predicted current and next year surface temperature anomaly values, choose one of the following. Then, justify your answer based on the relationship between the ENSO-DJ MEI2 Index and the temperature anomaly. In your justification, explain whether your prediction from Q9 was correct.

The current year ENSO-DJ is higher ***The next year ENSO-DJ is higher*** ***ENSO-DJ is the same (similar)***

____

____

Q13. Go to this link to access the MEI2 Index data. The first column contains the years 1979 to present, and the second column contains the ENSO-DJ values for each year.

In the data table, identify the two most recent years that contain an ENSO-DJ value, and then write the ENSO-DJ value for each year.

Year	ENSO-DJ

Based on the information in the data table, predict which year is likely to have a higher average temperature anomaly. Then, justify your answer.

Prediction: ________________________________

Justification: ____

____

EVALUATE

Base your answers to Q1 and Q2 on the content from the Engage, Explore, Explain, and Elaborate activities.

Q1. Explain why the El Niño Southern Oscillation (ENSO) and the Arctic Oscillation (AO) are referred to as teleconnections.

____

____

____

____

Q2. If the Arctic Oscillation (AO) is in its negative phase during the first five months of 2021, predict how the climate of Siberia will be impacted. Your prediction should include changes to temperature, pressure, and environmental conditions related to wildfires.

____

____

____

____

Q3. If the ENSO-DJ value of the MEI2 Index decreases this year to -0.55, predict how this change will impact the average global surface temperature anomaly in the next year. Then, justify your answer.

Prediction: ____

Justification: ____

____

Answers - Atmospheric Teleconnections Activity

Investigative Phenomenon – The change in temperature and pressure in one region of the world can influence weather patterns in another region.

ENGAGE

Step 1. Go to this link to watch the NASA video titled How the 2015-2016 El Niño Triggered Outbreaks Across the Globe. Scroll down towards the middle of the page to access the video. **Watch only the first minute.** While watching the video, write down any questions you have about the information presented.

Q1. Complete the chart below to demonstrate what you already know about the information in the first minute of the video, and what you are still wondering about the information. A strong response would include at least three **What I Know** statements, and three **What I am Wondering** statements. There is space for more statements, if needed!

What I Know	What I am Wondering
• Answers will vary based on each student	• Answers will vary based on each student
• Answers will vary based on each student	• Answers will vary based on each student
• Answers will vary based on each student	• Answers will vary based on each student
• Answers will vary based on each student	• Answers will vary based on each student

Step 2. With your small group, engage in a 5-minute Turn & Discuss based on the statements in the **What I am Wondering** column from Q1. Use the following guidelines during your discussion:

- Each group member will take turns sharing one statement from their **What I am Wondering** column.

- After each group member shares, the group will choose one of the **What I am Wondering** statements to focus on. This statement can be one that was repeated by more than one student, or a statement that intrigues the group the most!
- Use the remaining time to discuss the statement your group chose.

Refer to the Turn & Discuss Quality Criteria to help guide your discussion.

Step 3. One member from each group will share their groups' focus statement from step #2 with the class. Each **What I am Wondering focus statement** will be written on the board for the remainder of the ENGAGE activity.

Step 4. Go back and watch the remaining part of the video. After the video, use the space below to write down any information that relates to the **What I am Wondering focus** statements written on the board. You may use additional paper, if needed.

- **Answers will vary based on each student**
____
____
- **Answers will vary based on each student**
____
____
- **Answers will vary based on each student**
____
____
- **Answers will vary based on each student**
____
____
- **Answers will vary based on each student**
____
____

Q2. The following is a quote from a NASA article titled El Niño, which can be accessed at this link.

"El Niño is the largest natural disruption to the Earth system, with direct impacts across most of the Pacific Ocean. Indirect impacts reverberate around the globe in patterns that scientists refer to as "teleconnections.""

El Niño and the other phases of ENSO are not the only phenomena considered to have "teleconnections". Based on the quote and your knowledge of the widespread impacts of El Niño & the video from Q1, explain what you think the meaning of the term "teleconnection" is.

Answers will vary for each student. It is alright if the answer is incorrect as long as the students explain their reasoning.

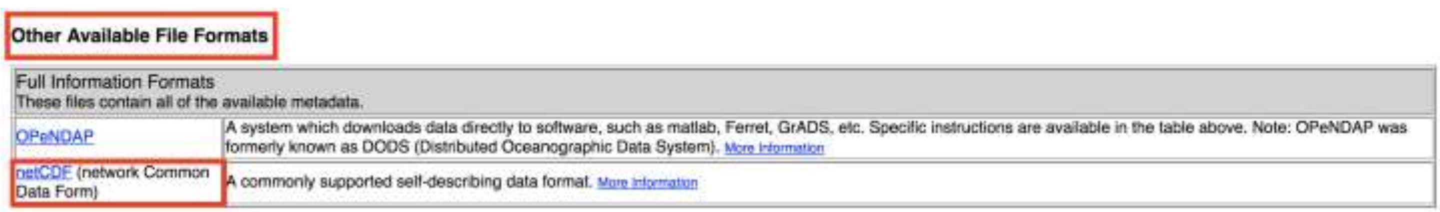
A model answer is a teleconnection refers to an event that is measured in one region of the world but can impact the climate in regions all around the world.

EXPLORE

Step 1. In this part of the activity you will be exploring another teleconnection known as the Arctic Oscillation (AO). The AO can be measured by the strength of low-pressure and high-pressure systems within the northern Atlantic Ocean.

Step 2. [Go to this link to access monthly average sea level pressure anomaly data from NOAA.] Then, look for the section titled **Other Available File Formats** and click on the link titled **netCDF,** as shown in the image below. This will download global average sea level pressure (SLP) anomaly data from January 1949 to June 2020*. The dataset contains 858 time slices, one for each month between January 1949 and June 2020*.

*__Note__: At the time this activity was created, the data was updated as of June 2020. As more time passes, the last month and year of the dataset will change to a later time. This will also increase the number of time slices.

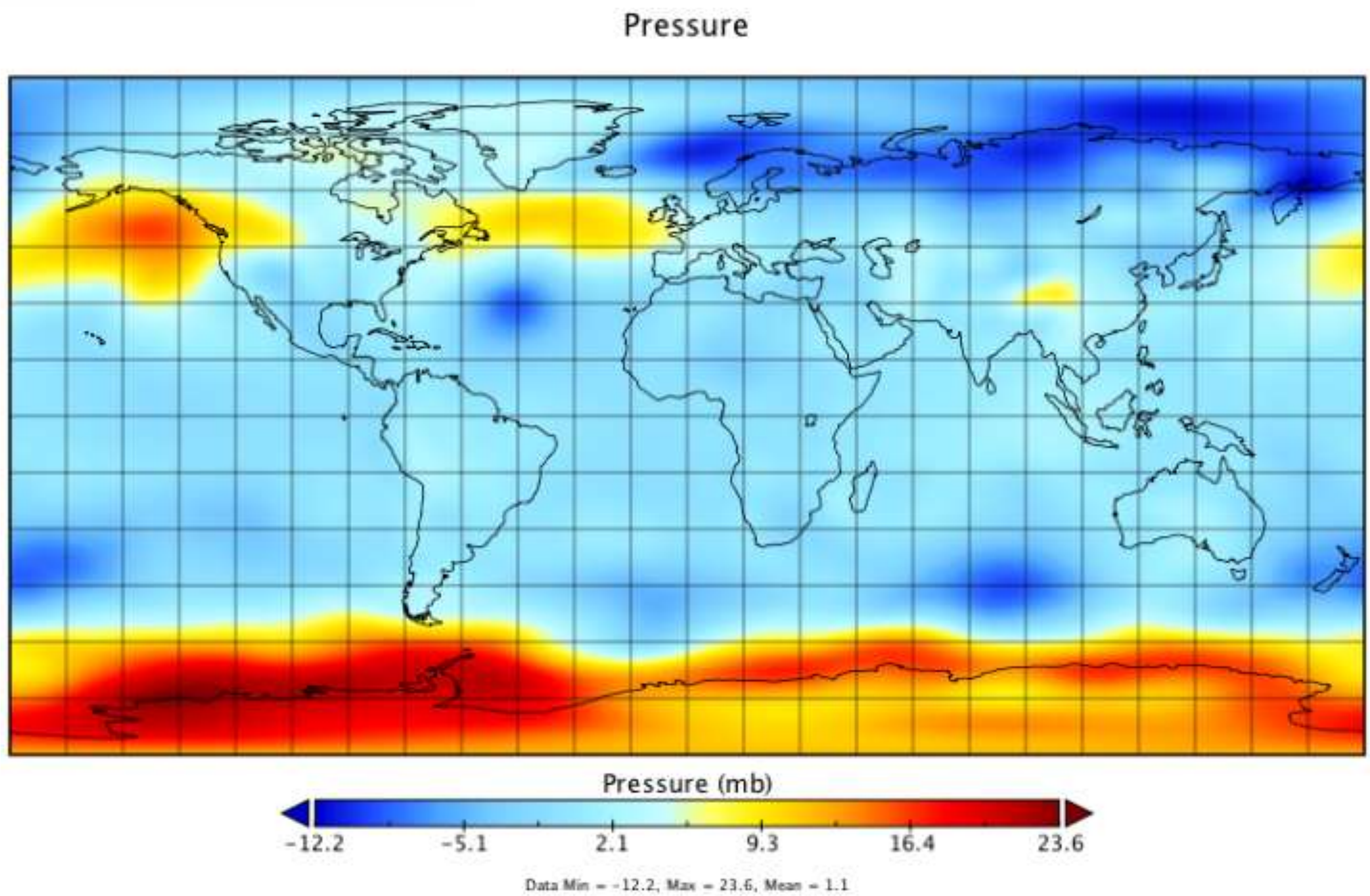


Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **data.nc.** Change the name of the file to **SLPAnomaly.nc** by right-clicking on the dataset and selecting "rename".

Step 3. Open the **SLPAnomaly.nc** dataset in Panoply.

Step 4. In Panoply, go to the **SLPAnomaly.nc** dataset and click on the variable titled **"pressure"**. Then, click **"Create Plot"** in the top left corner as shown below:

When prompted, click **Create** again and you should see a map that looks like the following:



Step 5. Go to the **Scale** tab near the bottom of Panoply and make the following changes, as shown in the image below:

- Change the **Scale Range: Min to -8** and the **Max to 8.**
- Change the **Color Table** to **CB_PRGn.cpt**
- Change the **Divisions, Major** to **4**.

Step 6. Next, go to the **Contours** tab and make the following changes, as shown in the image below:

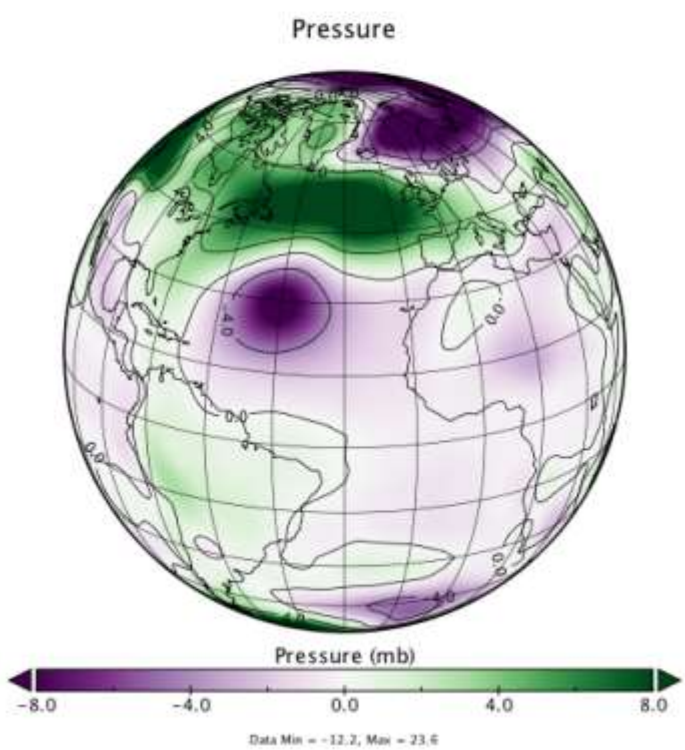
- Change the **Style** to **Solid**
- Check off the **box** for **Labels**
- Change the **Size** of the labels to **10**

Step 7. Go to the **Map** tab and make the following changes, as shown in the image below:

- Change the **Projection** to **Orthographic**.
- Change the **Center** on **Lon** to **-30˚E** and **Lat** to **20˚N.**

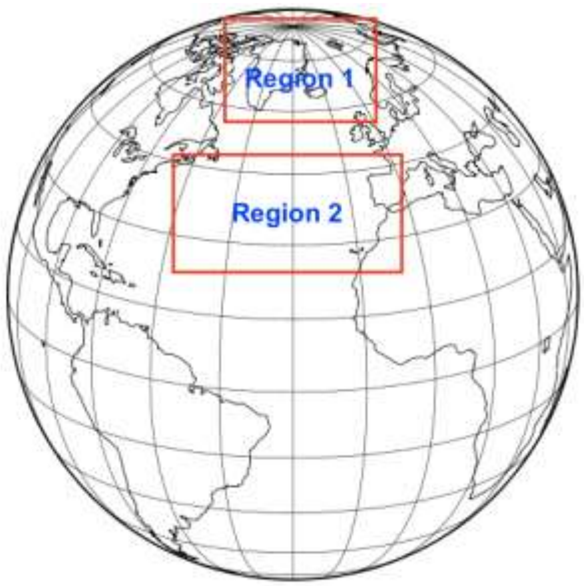
These changes result in a spherical map that is centered on the longitude -30˚E (30˚W) and latitude 20˚N so that the focus of the map is on the North Atlantic Ocean.

Step 8. You should now see a map that looks like the following:



The contour lines on the map represent lines of constant sea level pressure anomalies and accompany the color scale of the map.

Step 9. The Arctic Oscillation (AO) has two phases, positive AO & negative AO, and is influenced by the air pressure in two regions in the North Atlantic Ocean. Below is a map outlining the general regions in which air pressure can impact the AO.



Step 10. Go to the **Array(s)** tab near the bottom of Panoply and change the **Time** to **493** to represent sea level pressure anomalies during the month of January 1990 (1990-01-16), as shown in the image below.

During January 1990, the **AO** was in the **positive** phase.

Q1. Based on the locations of Region 1 (northern North Atlantic Ocean) and Region 2 (southern North Atlantic Ocean) shown in the image above from step #9, describe in general the sea level pressure anomalies during January 1990 within each region.

Region 1: **The sea level pressure anomalies are negative, representing below normal pressure**

Region 2: **The sea level pressure anomalies are positive, representing above normal pressure**

Q2. The sea level pressure anomalies in the two regions of the North Atlantic Ocean during January 1990 are examples of typical sea level pressure anomalies in those regions during the positive phase of the Arctic Oscillation.

Based on this information, how do you think scientists are able to classify a **positive AO** event?

Scientists are able to classify a positive AO event by the below normal sea level pressure anomalies in the northern North Atlantic Ocean (Region 1) and above normal sea level pressure anomalies in the southern North Atlantic Ocean (Region 2).

Step 11. Go to the **Array(s)** tab near the bottom of Panoply and change the **Time** to **734** to represent sea level pressure anomalies during the month of February 2010. During February 2010, the **AO** was in the **negative** phase.

Q3. Based on the locations of Region 1 (northern North Atlantic Ocean) and Region 2 (southern North Atlantic Ocean) shown in the image above from step #9, describe the general sea level pressure anomalies during February 2010 within each region.

Region 1: **The sea level pressure anomalies are positive, representing above normal pressure**

Region 2: **The sea level pressure anomalies are negative, representing below normal pressure**

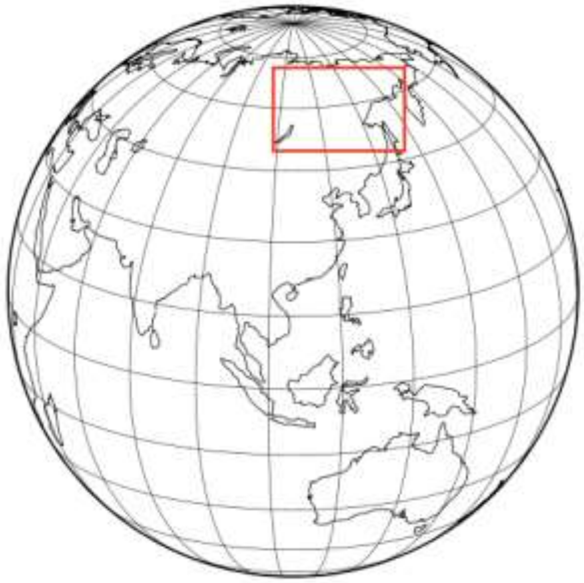
Q4. The sea level pressure anomalies in the two regions of the North Atlantic Ocean during February 2010 are examples of typical sea level pressure anomalies in those regions during the negative phase of the Arctic Oscillation.

Based on this information, how do you think scientists are able to classify a **negative AO** event?

Scientists are able to classify a negative AO event by the above normal sea level pressure anomalies in the northern North Atlantic Ocean (Region 1) and below normal sea level pressure anomalies in the southern North Atlantic Ocean (Region 2).

Step 12. Go back to the **Array(s)** tab and change the **Time** back to **493** to represent sea level pressure anomalies during the month of January 1990, a month in which the **AO** was in its **positive** phase.

Next, go to the **Map** tab and change the **Center on Lon** to **110˚E**. The map should now be centered on 110˚E longitude so the focus of the map is on eastern Russia, specifically eastern Siberia. The map below shows the region of interest.



Q5. In general, describe the sea level pressure anomalies in eastern Siberia during the **positive AO** event in **January 1990**. Use the image above from step #12 for regional guidance.

During a positive AO event, the sea level pressure anomalies in eastern Siberia are positive (above normal).

Step 13. Go to the **Array(s)** tab and change the **Time** back to **734** to represent sea level pressure anomalies during the month of February 2010, a month in which the **AO** was in its **negative** phase. Check to make sure the Lon is still centered on 110˚E longitude.

Q6. In general, describe the sea level pressure anomalies in eastern Siberia during the **negative AO** event in February 2010. Use the image above from step #12 for regional guidance.

During a negative AO event, the sea level pressure anomalies in eastern Siberia are mostly negative (below normal).

Q7. Based on the sea level pressure anomalies in eastern Siberia in January 1990, what can you conclude about the change in air pressure in eastern Siberia during **positive phases of the Arctic Oscillation** (AO)?

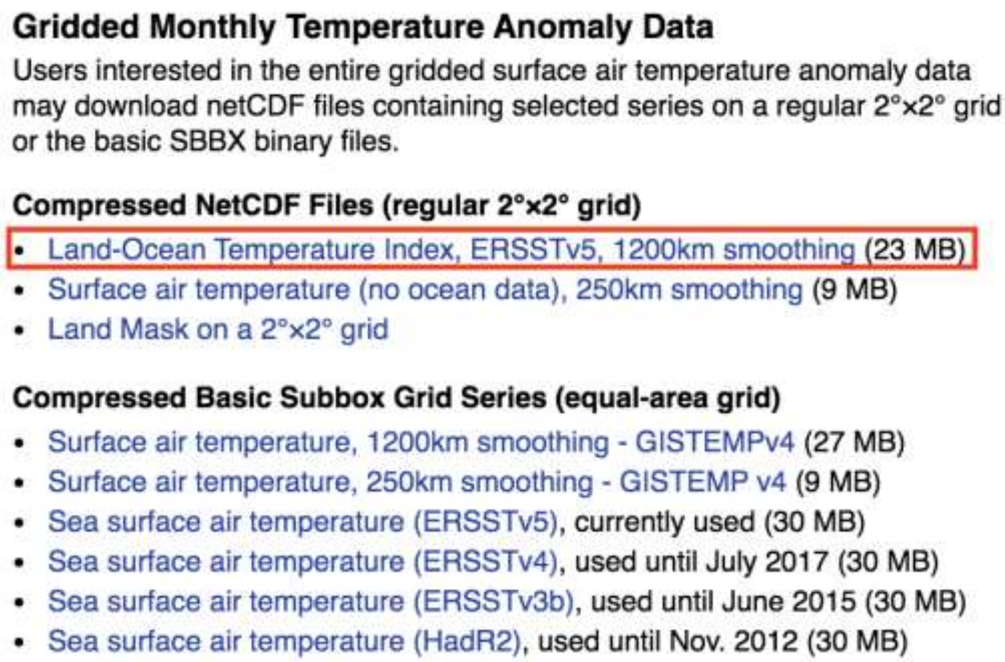
During positive phases of the AO, the air pressure in eastern Siberia increases.

Q8. Based on the sea level pressure anomalies in eastern Siberia in February 2010, what can you conclude about the change in air pressure in eastern Siberia during **negative phases of the Arctic Oscillation** (AO)?

During negative phases of the AO, the air pressure in eastern Siberia decreases.

Step 14. [Go to this link to access surface temperature anomaly data from NASA's GISTEMP.]() Scroll down towards the bottom of the page to a section titled **Gridded Monthly Temperature Anomaly Data**, and click on the link titled **Land-Ocean Temperature Index, ERSSTv5, 1200km smoothing** to download average monthly surface temperature anomaly data, as shown in the image below. The data is from January 1880 to June 2020*, which results in 1686 time slices, one for each month between January 1880 and June 2020.

*__Note__: At the time this activity was created, the data was updated as of June 2020. As more time passes, the last month and year of the dataset will change to a later time. The number of time slices will also increase.



Gridded Monthly Temperature Anomaly Data

Users interested in the entire gridded surface air temperature anomaly data may download netCDF files containing selected series on a regular 2°×2° grid or the basic SBBX binary files.

Compressed NetCDF Files (regular 2°×2° grid)

- Land-Ocean Temperature Index, ERSSTv5, 1200km smoothing (23 MB)
- Surface air temperature (no ocean data), 250km smoothing (9 MB)
- Land Mask on a 2°×2° grid

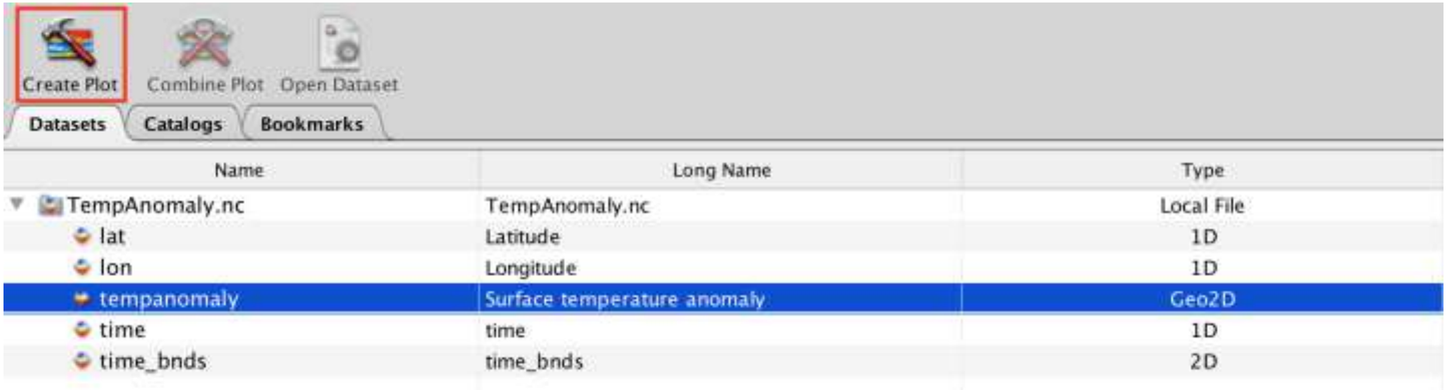
Compressed Basic Subbox Grid Series (equal-area grid)

- Surface air temperature, 1200km smoothing - GISTEMPv4 (27 MB)
- Surface air temperature, 250km smoothing - GISTEMP v4 (9 MB)
- Sea surface air temperature (ERSSTv5), currently used (30 MB)
- Sea surface air temperature (ERSSTv4), used until July 2017 (30 MB)
- Sea surface air temperature (ERSSTv3b), used until June 2015 (30 MB)
- Sea surface air temperature (HadR2), used until Nov. 2012 (30 MB)

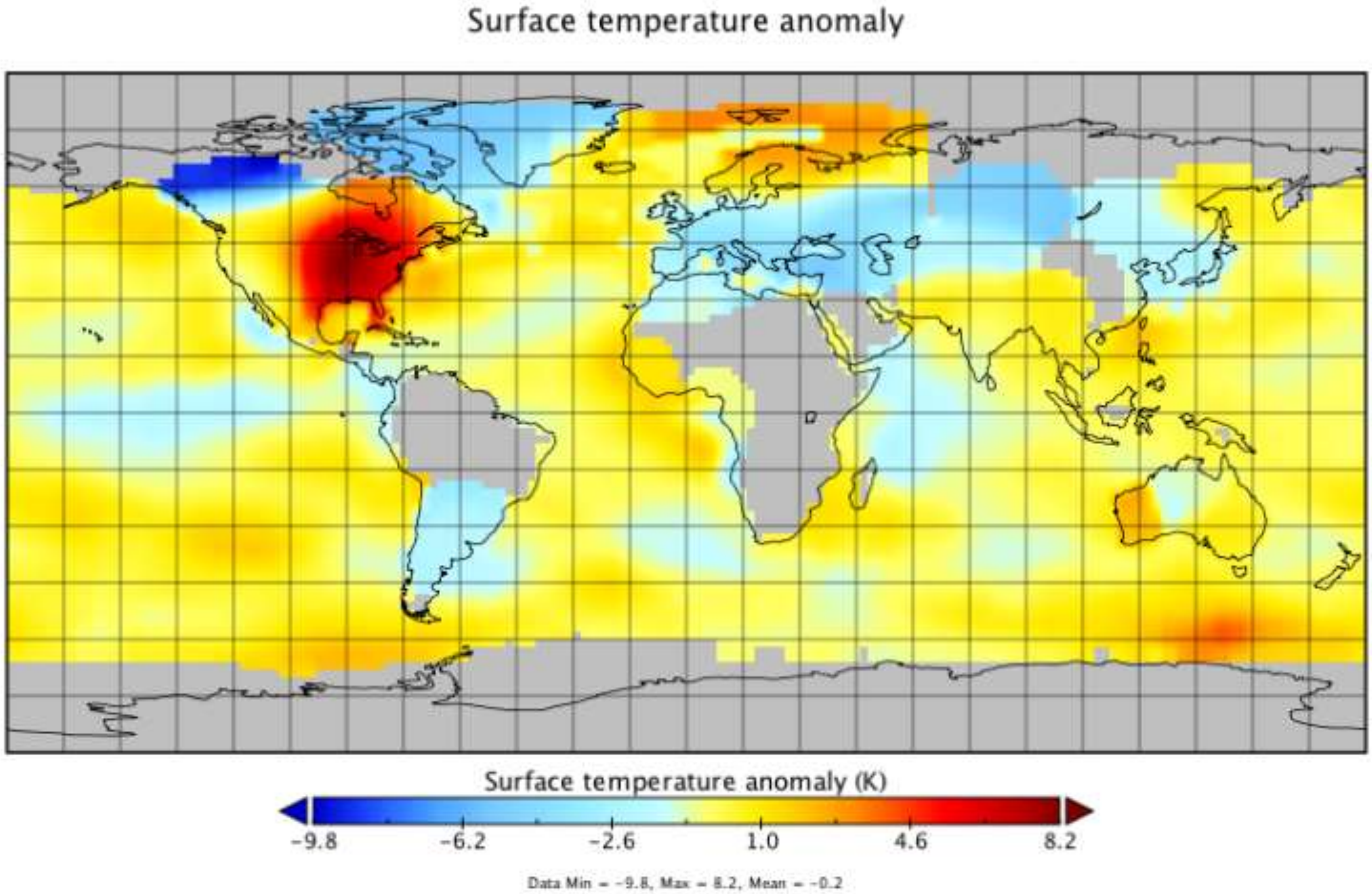
Downloaded data should be located in the **Downloads** folder of your computer. The downloaded file is named **gistemp1200_GHCNv4_ERSSTv5.nc.** Change the name of the file to **TempAnomaly.nc** by right-clicking on the dataset and selecting “rename”.

Step 15. Open the **TempAnomaly.nc** dataset in Panoply.

Step 16. In Panoply, go to the **TempAnomaly.nc** dataset and click on the variable titled **“tempanomaly”** and then click **“Create Plot”** in the top left corner as shown below:



When prompted, click **Create** again and you should see a map that looks like the following:



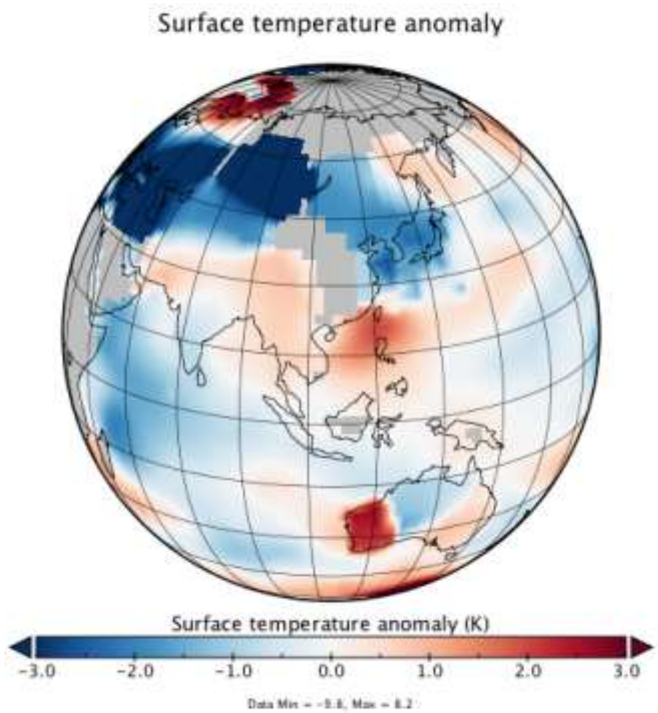
Step 17. Go to the Scale tab and make the following changes, as shown in the image below:

- Change the **Scale Range: Min to -3** and the **Max to 3.**
- Change the **Divisions, Major** to **6**.
- Change the **Color Table** to **CB_RdBu.cpt**
- Check the box for **Reverse colors**

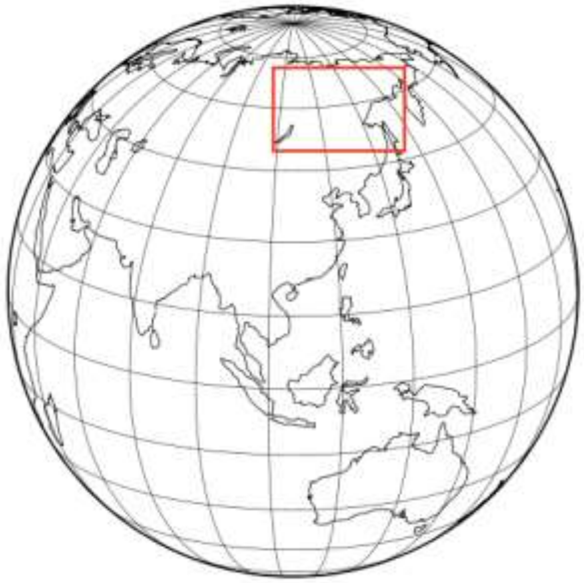
Step 18. Go to the **Map** tab and make the following changes, as shown in the image below:

- Change the **Projection** to **Orthographic**.
- Change the **Center** on **Lon** to **110˚E** and **Lat** to **20˚N.**

Step 19. You should now see a map that looks like the following:



Step 20. Go to the **Array(s)** tab near the bottom of Panoply. Starting at **Time 1321,** slowly change the **Time** to **1322**, then **1323**, and **1324** to display the surface temperature anomalies from January 1990 to April 1990. During these months the **Arctic Oscillation** was in its **positive** phase. Focus specifically on the surface temperature anomalies in the eastern Siberia region outlined in the map below, which is the same as the one provided above in step #12.



Q9. In general, describe the overall surface temperature anomalies in eastern Siberia from January 1990 to April 1990, a time when the Arctic Oscillation was in its positive phase.

During the positive AO event, in general the surface temperature anomalies in eastern Siberia were positive, indicating that surface temperature was higher than normal.

Step 21. Go to the **Array(s)** tab near the bottom of Panoply. Starting at **Time 1560**, slowly change the **Time** to **1561**, then **1562**, then **1563,** and **1564** to display the surface temperature anomalies from December 2009 to April 2010. During these months the **Arctic Oscillation** was in its **negative** phase. Focus specifically on the surface temperature anomalies in the eastern Siberia region.

Q10. In general, describe the overall surface temperature anomalies in eastern Siberia from December 2009 to April 2010, a time when the Arctic Oscillation was in its negative phase.

During the negative AO event, in general the surface temperature anomalies in eastern Siberia were negative for most months, indicating that surface temperature was lower than normal.

Q11. Based on the surface temperature anomalies in eastern Siberia from January 1990 to April 1990, what can you conclude about the change in surface temperature in eastern Siberia during **positive phases of the Arctic Oscillation** (AO)?

During positive phases of the AO, surface temperature anomalies in eastern Siberia are generally positive, indicating higher than normal surface temperature.

Q12. Based on the sea level pressure anomalies in eastern Siberia from December 2009 to April 2010, what can you conclude about the change in surface temperature in eastern Siberia during **negative phases of the Arctic Oscillation** (AO)?

During negative phases of the AO, surface temperature anomalies in eastern Siberia are generally negative, indicating lower than normal surface temperature.

Q13. The Arctic Oscillation (AO) is another example of a teleconnection. The AO can be measured by the strength of low-pressure and high-pressure systems within the northern Atlantic Ocean. Based on what you learned about the AO and also El Niño, define the meaning of "teleconnection".

A teleconnection is any climate event that occurs in one location and can impact the climate in other regions around the world.

EXPLAIN

Step 1. Read the information provided in the excerpt below from UCAR Center for Science Education to learn about the meaning of the term "teleconnections". The excerpt can also be accessed from this UCAR website about teleconnections.

Changes in the atmosphere in one place can affect weather over 1000 miles away. Scientists are trying to sort out how this works so that they can better understand and predict weather patterns worldwide. They call these patterns teleconnections.

Teleconnection patterns are caused by changes in the way air moves around the atmosphere. The changes may last from a few weeks to many months. Teleconnection patterns are natural. However, they may be changed as Earth's climate warms.

Q1. Based on the information given above, define teleconnection.

A teleconnection is a change in atmospheric conditions in one location that can influence the weather patterns worldwide.

Q2. An El Niño event characterized by higher than normal sea surface temperature anomalies in the eastern equatorial Pacific Ocean can increase temperatures along the northwest coast of North America.

Explain why El Niño events are considered to have teleconnections.

El Niño events are considered to have teleconnections because the change in sea surface temperature in one region is impacting the temperature in a different region.

Q3. The positive phase of the Arctic Oscillation is characterized by lower than normal sea level pressure in the northern region of the North Atlantic Ocean (near Greenland) and higher than normal sea level pressure anomalies in the southern region of the North Atlantic Ocean. A positive AO event can lead to higher than normal surface temperature in eastern Siberia.

Explain why the Arctic Oscillation is considered to be a teleconnection.

The Arctic Oscillation is considered to be a teleconnection because the change in sea level pressure in the North Atlantic Ocean can influence the surface temperature in far-away eastern Siberia.

Step 2. Go to this link to access information from the National Snow & Ice Data Center about the Arctic Oscillation.

Step 3. Before you read the text, read Q4 through Q11 below to learn the content you should focus on. Then, read the entire text.

Once you read the text, answer Q4 through Q11.

Q4. The beginning of the text references how the Arctic Oscillation (AO) has influenced winter weather patterns in the United States. How does the **negative mode** (phase) of the AO influence weather in the United States during the winter?

The negative phase of the AO can lead to an increase in winter storms in the Northeastern United States.

Q5. The beginning of the text references how the Arctic Oscillation (AO) has influenced winter weather patterns in the United States. How does the **positive mode** (phase) of the AO influence weather in the United States during the winter?

The positive phase of the AO can lead to warmer than normal temperature and decreased snowfall in the United States.

Q6. The Arctic Oscillation is based on pressure patterns in which two general regions?

(1) The Arctic region (approximately 66.5˚N to 90˚N latitude)

(2) Middle latitudes of the Northern Hemisphere

Q7. In general, the change in mode of the Arctic Oscillation influences a change in what?

The change in mode of the Arctic Oscillation influences a change in atmospheric circulation, specifically the way the wind blows.

Q8. Describe the general air pressure patterns in both regions identified in Q6 during the **negative** mode of the AO.

During the negative mode of the AO, the pressure is higher than normal over the Arctic (positive anomaly) and lower than normal over the middle latitudes (negative anomaly).

Q9. Describe the general air pressure patterns in both regions identified in Q6 during the **positive** mode of the AO.

During the positive mode of the AO, the pressure is lower than normal over the Arctic (negative anomaly) and higher than normal over the middle latitudes (positive anomaly).

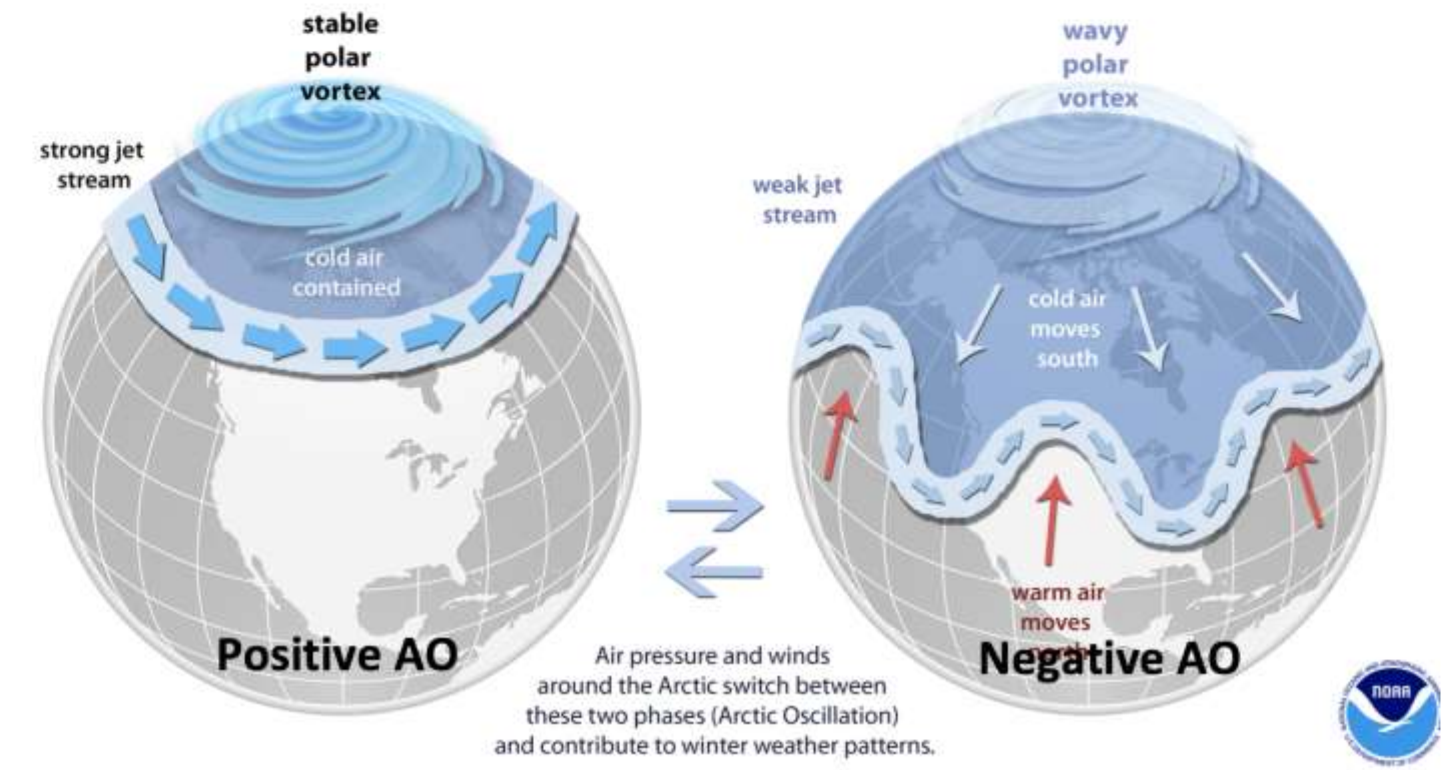
Q10. During the **positive** mode of the AO, explain why storms shift further north in the winter, leaving locations in the mid-latitudes drier and warmer than normal.

During the positive mode of the AO, storms shift further north in the winter because the jet stream shifts further north. This leaves the mid-latitudes with less storms and warmer temperatures.

Q11. During the **negative** mode of the AO, explain why there are more snowstorms in the winter in the mid-latitudes.

During the negative mode of the AO, there are more snowstorms in the mid-latitudes because jet stream moves further south, bringing the storms with it.

Step 4. The image below from NOAA shows the changes to atmospheric circulation through the jet stream during the positive AO (left) and negative AO (right). The jet stream is a band of strong winds in the upper atmosphere that travels from west to east and acts as a boundary between cold air to the north and warmer air to the south.



Q12. Based on the image above, describe what happens to the cold polar air from the polar vortex when the AO is both positive and negative.

+ AO: **The cold air from the polar vortex is confined to the Arctic regions due to a strong jet stream and stays to the north.**

- AO: **The cold air from the polar vortex moves southward towards the mid-latitudes due to a weak jet stream.**

Q13. There are two sets of blank maps on the following page, one set is titled **Positive AO** and the other set is titled **Negative AO**. Within each set of maps, there is one centered on the North Atlantic Ocean, and the other is centered on Siberia. Use the symbols below to complete the following task:

- **Positive AO**: Label the map centered over the North Atlantic Ocean based on the air pressure trends in the mid-latitudes of the North Atlantic Ocean and the Arctic. The symbols need to be drawn in the correct locations on the map.

- **Negative AO**: Label the map centered over the North Atlantic Ocean based on the air pressure trends in the mid-latitudes of the North Atlantic Ocean and the Arctic. The symbols need to be drawn in the correct locations on the map.

Symbols:

H = Higher than normal pressure **L** = Lower than normal pressure

Q14. From January 2020 to June 2020, Siberia experienced warmer than normal temperatures, leading to drier conditions conducive to wildfires. According to an article from the NASA Earth Observatory titled Heat and Fire scorches Siberia, a persistent high-pressure system is responsible for the positive temperature anomalies and dry conditions. From January to April 2020, the AO was in its positive mode.

- **Positive AO**: Use the symbols from Q13 to label the map centered over Siberia with the correct air pressure trend over Siberia.

- **Negative AO**: Use the symbols from Q13 to label the map centered over Siberia with the correct air pressure trend over Siberia.

Q15. Based on what you have learned about the Arctic Oscillation thus far, complete the following tasks:

- On both maps for each phase of the AO (four maps total), gently shade the Arctic Circle light blue to represent the location of cold Arctic air from the polar vortex. The shading should be the same on all maps.

Q16. There are two tasks below.

- On both Positive AO maps, draw arrows with a purple colored pencil to show the strong movement of a northern jet stream that confines the cold air from the polar vortex within the Arctic.

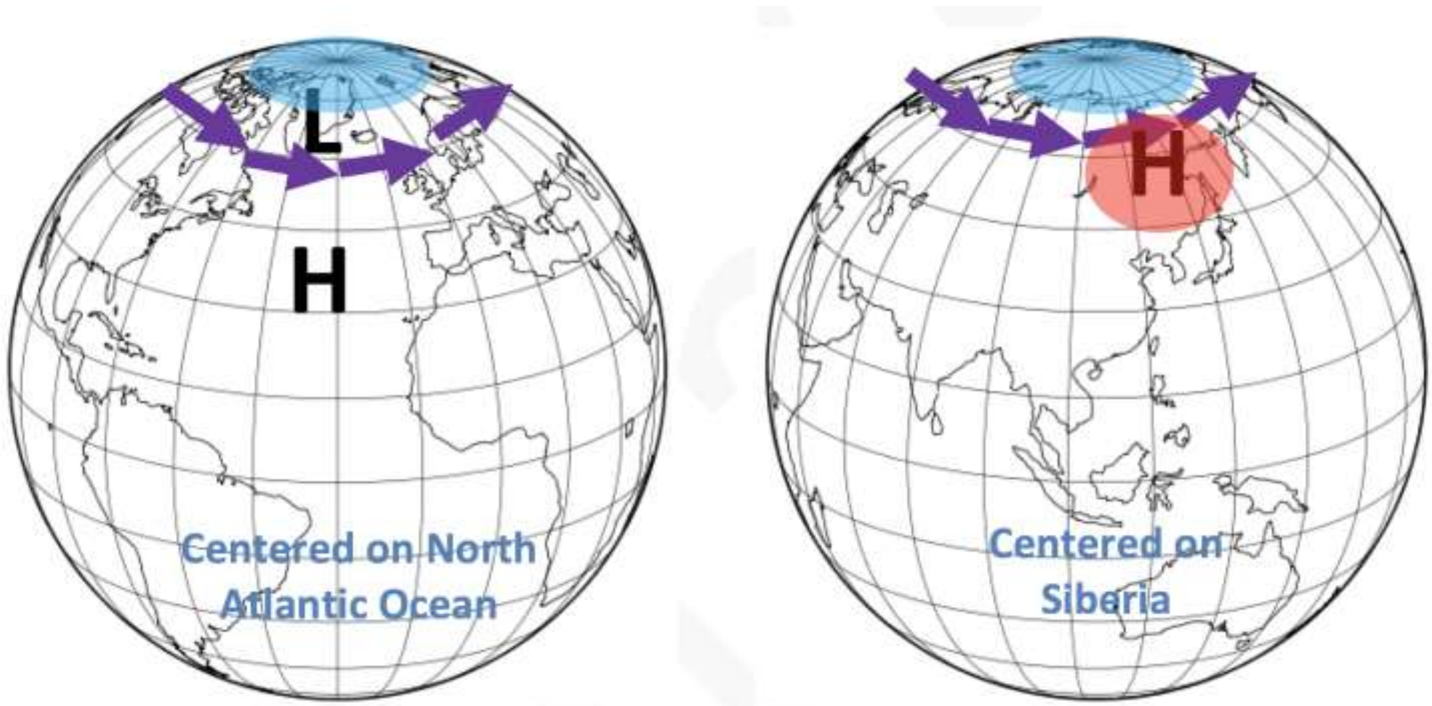
- On both Negative AO maps, draw arrows with a purple colored pencil to show the southward movement of the cold air from the polar vortex due to the southward shift of the jet stream.

Q17. Complete the tasks below using only the map centered over Siberia.

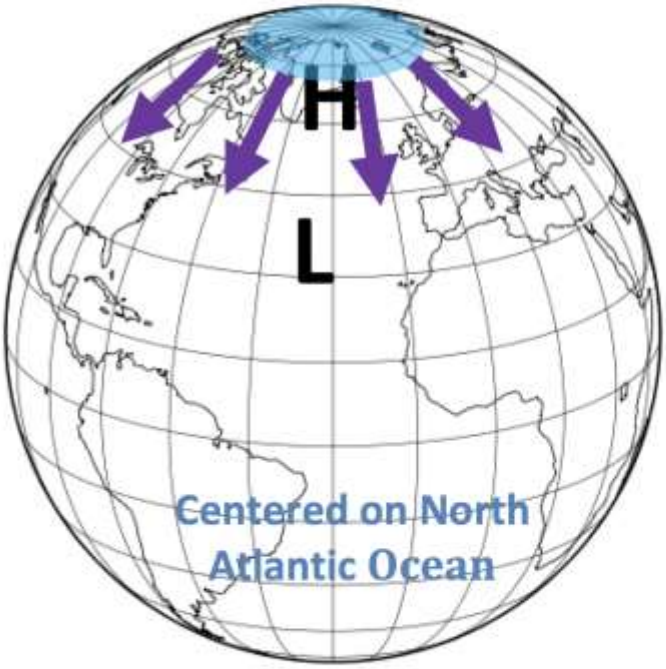
- **Positive AO**: Gently shade eastern Siberia with a dark blue or red colored pencil to represent whether temperature is lower than normal or higher than normal, respectively.

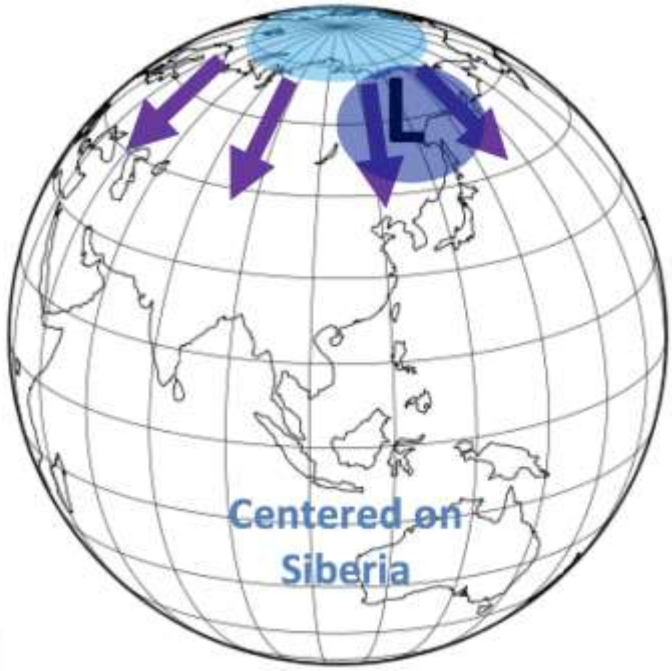
- **Negative AO**: Gently shade eastern Siberia with a dark blue or red colored pencil to represent whether temperature is lower than normal or higher than normal, respectively.

Positive AO



Negative AO





Q18. Based on what you have learned about the Arctic Oscillation thus far, explain how the **positive phase** of the AO influences the pressure and temperature over eastern Siberia. Your answer should include a description of how temperature and pressure change, and why the change occurs.

During a positive phase of the AO, the air pressure over eastern Siberia increases and air temperature also increases. This occurs because during a +AO event, the jet stream stays in the Arctic, confining the cold air to that region.

Q19. Based on what you have learned about the Arctic Oscillation thus far, explain how the **negative** phase of the AO influences the pressure and temperature over eastern Siberia. Your answer should include a description of how temperature and pressure change, and why the change occurs.

During a negative phase of the AO, the air pressure over eastern Siberia decreases and air temperature also decreases. This occurs because during a -AO event, the jet stream shifts further south, allowing cold air from the polar vortex to also shift further south.

Q20. From January 2020 to June 2020, Siberia has been experiencing warmer than normal temperatures, leading to drier conditions conducive to wildfires. More information about this can be found at this article from the NASA Earth Observatory titled Heat and Fire scorches Siberia.

Explain how the Arctic Oscillation played a role in the heat wave that resulted in environmental conditions conducive to wildfires. Your answer should include the phase of the AO, and its impact on pressure and temperature in Siberia.

In the beginning of 2020, the Arctic Oscillation was in its positive phase. This led to an increase in air pressure over Siberia and an increase in temperature. The lack of precipitation and higher than normal temperatures resulted in dry conditions conducive to wildfires.

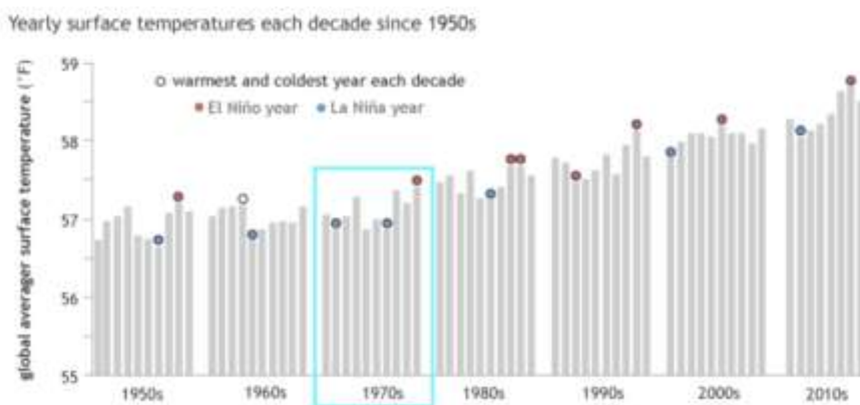
ELABORATE

Step 1. Atmospheric teleconnections like the Arctic Oscillation (AO) and El Niño Southern Oscillation (ENSO) can have a large impact on both local and global climate. In the EXPLORE and EXPLAIN activities you had the opportunity to learn how the Arctic Oscillation can impact local climate through the heat waves and wildfires in Siberia. In this ELABORATE activity, you will investigate how ENSO can impact global temperatures as a teleconnection.

Go to this link from NOAA to read how the phases of ENSO has impacted average global temperature since the 1950s. Scroll down to the section titled **How does ENSO affect global temperature**, as shown in the image below, and read the text in that section.

> **How does ENSO affect global average temperature?**
>
> Within any given decade, the warmest years are usually El Niño ones, and the coldest are usually
>
> La Niña ones. That's because the Pacific Ocean is a big place. If you walked around the planet

Step 2. The graph titled **Yearly surface temperature each decade since the 1950s** shows the average global temperature for each year from 1950 to 2017. Each year is grouped into a decade representing the 1950s, 1960s, 1970s, 1980s, 1990s, 2000s, or 2010s. An example of the years grouped in the 1970s decade is shown below.



In each decade, the highest and lowest average global temperature is marked with a circle. Each circle is colored to represent the El Niño, La Niña, or Neutral phrase of ENSO. The color codes are:

- White circle = Neutral ENSO
- Red circle = El Niño
- Blue circle = La Niña

Note: Some decades have more than one circle for highest and lowest temperature due to repeats in the record.

Q1. How many times was the **Neutral phase of ENSO** occurring when the **highest** temperature was recorded in each decade?

1

Q2. How many times was the **El Niño phase of ENSO** occurring when the **highest** temperature was recorded in each decade?

6

Q3. How many times was the **La Niña phase of ENSO** occurring when the **highest** temperature was recorded in each decade?

0

Q4. Based on your answers to Q1 – Q3 and the data from the **Yearly surface temperature each decade since the 1950s** graph, what conclusion can you make about the phase of ENSO and global average temperature?

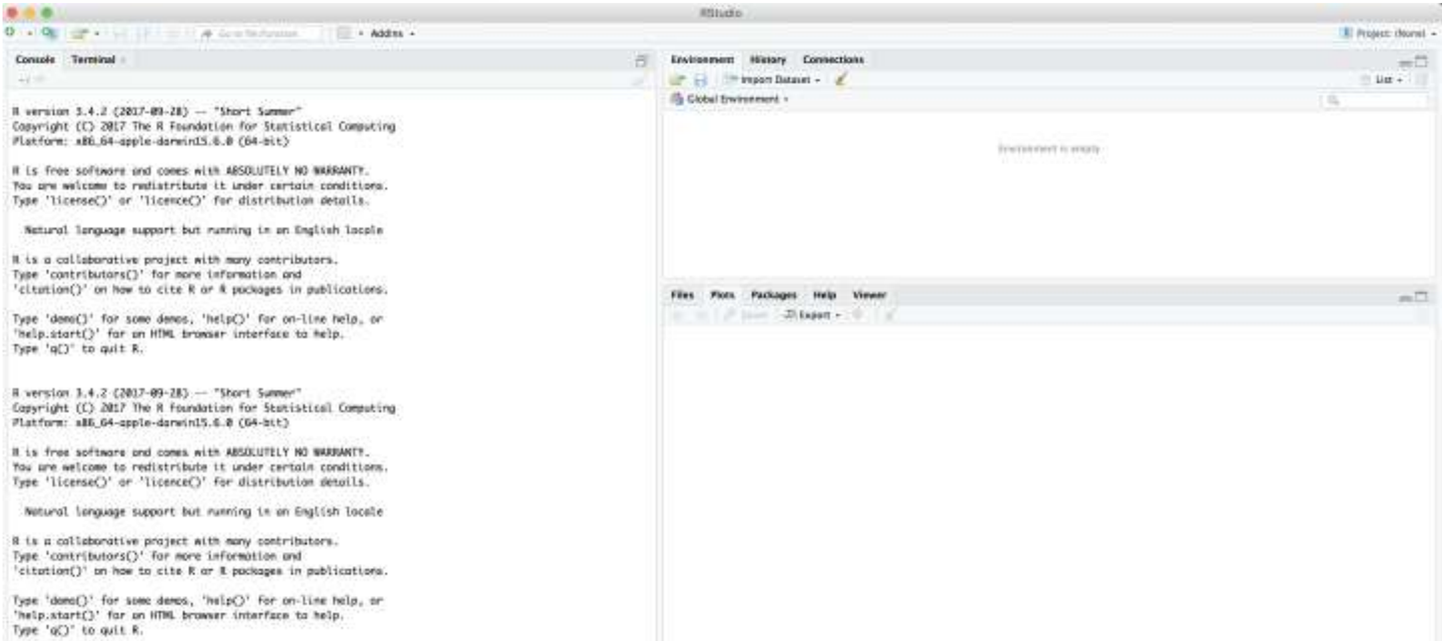
Global average temperature is generally higher during El Niño years (positive phase of ENSO).

Step 3. NASA GISS scientists Nathan Lenssen, Gavin Schmidt, James Jansen, Matthew Menne, Avraham Persin, Reto Ruedy, and Daniel Zyss have been exploring how the December/January phase of ENSO can be used to predict average global temperature for the upcoming year. For example, the December 2017/January 2018 ENSO phase can be used to predict the average global temperature for 2018.

To do this, the NASA GISS Scientists created a code using the R programming language that utilizes global temperature anomaly data from NASA's GISTEMP and the Multivariate El Niño Southern Oscillation 2 (MEI2) Index.

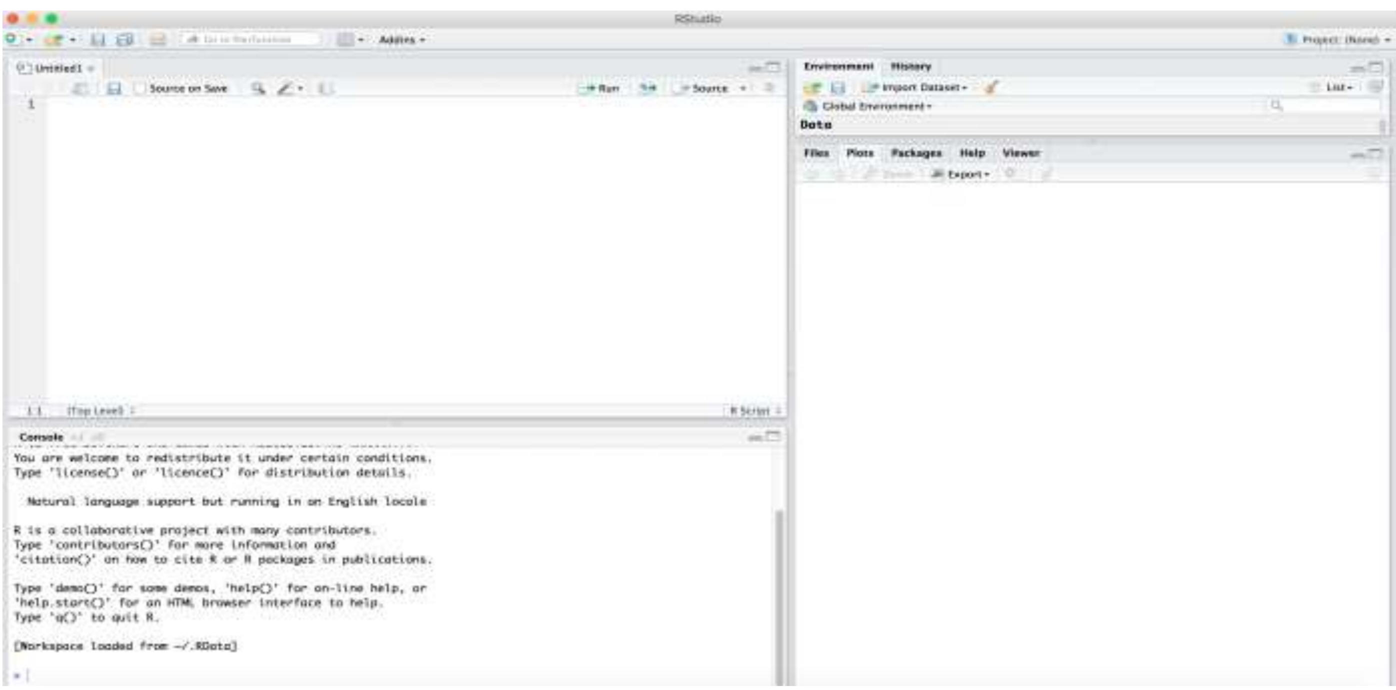
Step 4. Ensure that Rstudio is installed on your computer. If RStudio is not downloaded on your computer, please complete the download instructions provided by your teacher.

Step 5. Open RStudio and you will see a screen that looks like this.



Step 6. At the top left of Rstudio, click on **File**, then **New File,** and then click **R Script**.

Step 7. You should now see the following on your screen in the image below. The image shows a blank script in the top left of the program, and now the Console is on the bottom left of the program.



Step 8. The ***top left panel*** of RStudio contains the **R Script** that will be used to write code with the R programming language. Once a script is created, a user can run the entire script or run the script line by line or section by section.

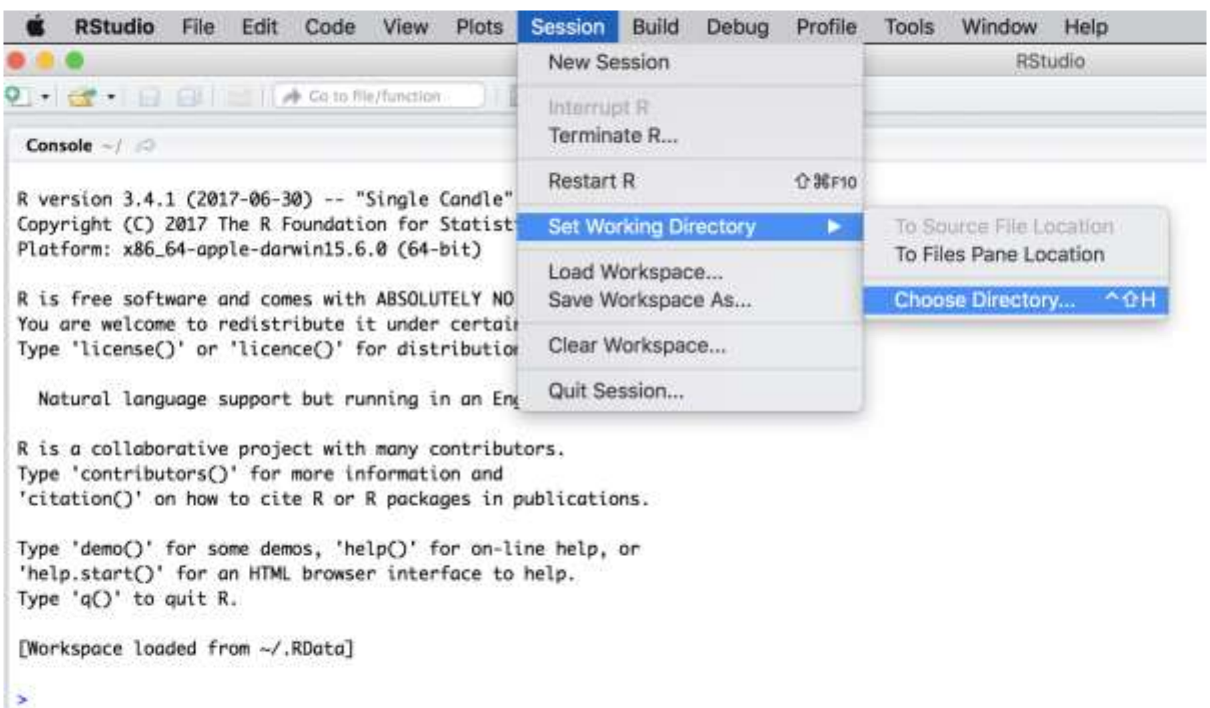
The ***bottom left panel*** of RStudio contains the **Console** which displays the lines of code that the user selects to run. Users can also type commands and perform calculations directly in the **Console** for a quick answer rather than writing a script and waiting for an answer after running the script.

The ***top right side*** of RStudio contains an **Environment tab** which lists all of the datasets that have been loaded into RStudio. There is also a **History tab** that contains the history of everything that was typed into the **Console**.

The ***bottom right side*** of RStudio contains a **Plot tab** that allows users to look at any plots that are created. There is a **Packages tab** that allows users to download packages that are needed for specific R tasks, and there is a **Help tab** that allows users to search how to use specific commands in R.

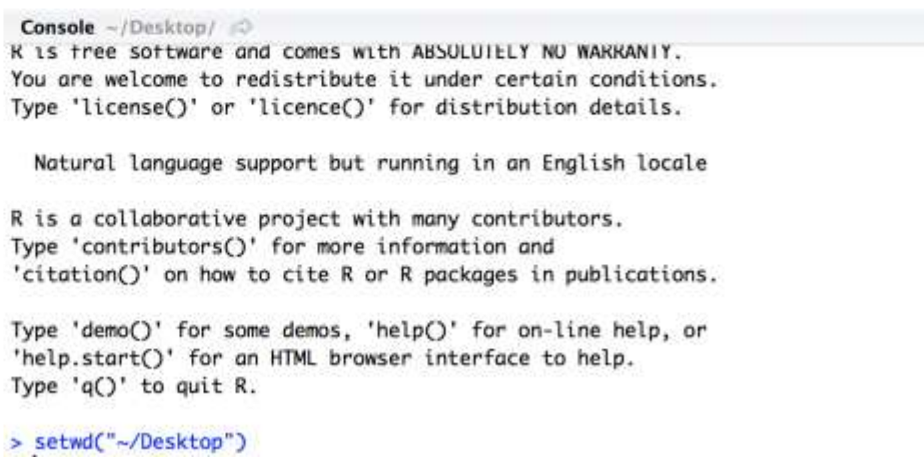
Step 9. We will begin by setting our **Working Directory** in Rstudio. A **Working Directory** is the location/folder on your computer where you want your work to be stored. A **Working Directory** could be the Documents folder of your computer, the Downloads folder, Desktop folder, or any other folder. For this activity, we will all be using the **Desktop** folder as our **Working Directory**.

To set your Working Directory in RStudio, go to **Session** at the top, then click on **Set Working Directory**, and then click on **Choose Directory**, as shown in the image below.



A window will pop-up depending on your computer, which could be similar to the image below. Click on the **Desktop** folder and then click **Open**.

The **Working Directory** should now be set to the Desktop folder, and the **Console** should look like the following:



The command **setwd("~/Desktop")** in the blue font in the Console is a result of setting your working directory. The top left of the Console should now show that the Desktop folder is the **Working Directory**, as shown in the image below:

Step 10. Make sure you have the **GISTEMP_Download.R** script provided by your teacher saved in your Desktop folder.

Step 11. Make sure you have the **MEI2_Download.R** script provided by your teacher saved in your Desktop folder.

Step 12. When RStudio is first downloaded, it comes with a default set of commands and libraries. To complete this activity, users need to install the **sm and gdata** libraries. These libraries are needed for RStudio to do statistical calculations within the code.

Go to the **Console** and ***type*** **install.packages("sm")** and then press enter. The library package will download in the **Console**.

Then, go to the **Console** and ***type*** **install.packages("gdata")** and then press enter. The library package will download in the **Console**.

Step 13. Once a library is downloaded, it does not need to be downloaded again. However, it does need to be referenced at the top of every R Script that uses the **sm and gdata libraries**. It is always a great idea to reference the libraries needed in each script at the top of the code.

Open another blank RScript and save it as **Temperature_Predictions.R**

On line #1 of the code type **library(sm)**

On line #2 of the code type **library(gdata)**

Library is a command in line #1 and there, you are referencing the **sm library** with the library command. On line #2, you are referencing the **gdata library**.

Step 14. Within the code statements can be written that explain the function of the steps that follow. The statements need to be "commented out", which means the writing will not be part of the code when the code is later running.

In the R language, the symbol "#" needs to be placed in the beginning of each line of the code that is meant to be commented out. For example:

#This statement is written to teach students how to comment out a line in a R code.

Later when the code you write is running, R Studio will not include any line that is commented out in the calculations or procedures you are performing in your code.

Step 15. On line #4 in the RScript, write the following comment:
#Run the GISTEMP_Download.R and MEI2_Download.R scripts to download the gistemp_v4_mon.lp and MEI2.txt datasets

Step 16. We will now write statements that will run the **GISTEMP_Download.R** and **MEI2_Download.R** scripts you downloaded from your teacher earlier.

First will be the **GISTEMP_Download.R** file. To run this script, we need to use a command called **source**. The only argument we will use in the **source** command is **file**, which is the file name of **GISTEMP_Download.R.** Since this file should already be in the Desktop folder of your computer, which is your working directory, you do not need to provide the entire file pathway.

On line #5 of the script, write the following:

source("GISTEMP_Download.R")

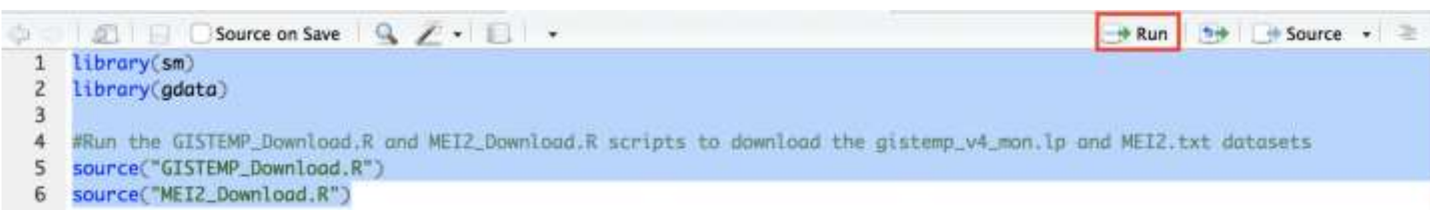
On line #6 of the script, write the following to source the **MEI2_Download.R** script:

source("MEI2_Download.R")

Step 17. Your RScript should now look similar to the following:

```
1  library(sm)
2  library(gdata)
3
4  #Run the GISTEMP_Download.R and MEI2_Download.R scripts to download the gistemp_v4_mon.lp and MEI2.txt datasets
5  source("GISTEMP_Download.R")
6  source("MEI2_Download.R")
```

Step 18. Highlight and run lines 1 through 6 in the code, as shown in the image below.



Check the Console to see if there are any error messages. If there are no error messages, your Console should show verification that the data was downloaded.

If there are error statements in the **Console**, it is most likely due to an incorrect file pathway in the source commands from lines #5 and #6. If you are unsure about your error statement, it can be helpful to copy and paste the error message into Google to learn more about your error.

Step 19. Now that the data we need is loaded into RStudio, we need to source the RScript that contains all of the calculations. These calculations lead to annual global temperature anomalies and statistical analyses between the temperature anomaly and MEI2 data. The source RScript also creates plots for further analysis.

The source RScript will be provided to you by your teacher and is titled **Temperature_Predictions_Source.R**

Once you receive the **Temperature_Predictions_Source.R** file, be sure to save it to your **Desktop** folder. **Do not change the name of the file!**

Step 20. On line #8 of the code, write the following commented statement:
#Source the Temperature_Predictions_Source.R script. This RScript contains the code that performs all of the calculations and makes plots for further analysis.

Step 21. To source a RScript, we need to use the **source** command. The only argument we will use in the **source** command is **file**, which is the pathway to the **Temperature_Predictions_Source.R**

On line #9 of the code, write the **source** command with your file pathway to **Temperature_Predictions_Source.R** in parentheses.

An example of line #9 is shown below:

source("Temperature_Predictions_Source.R")

Step 22. Highlight and run line #9 of the code to execute the source **Temperature_Predictions_Source.R** script and check the **Console** to ensure there are no error statements. If there are no errors, your **Console** will look similar to the image below:

```
> source("Temperature_Predictions_Source.R")
[1] "The plot may be saved to a pdf file by either"
[1] "   changing the above line to :"
[1] "                         savepdf<-1"
[1] "Then re-running this script"
[1] "Or from your computer's command line::"
[1] "          Rscript Temperature_Predictions_Source.R 1"
[1] "Previous max(es) ( 2016 ): 1.02" "Previous max(es) ( 2020 ): 1.02"
[1] "2021 prediction based on YTD vs. Annual average regression 0.71 +/- 0.25 °C"
[1] "2021  prediction (based on ENSO in Dec/Jan): 1.01 +/- 0.22 °C"
[1] "2022  prediction (based on projected ENSO in Dec/Jan): 1.18 +/- 0.23 °C"
```

The last two predictions are of interest in this activity. These predictions are as of the current year 2021 and will be different as time goes on.

If there are errors in the Console, it is likely due to the location of the **Temperature_Predictions_Source.R** file. Please make sure the **Temperature_Predictions_Source.R** file is in the Desktop folder of your computer, and that the working directory for RStudio is set to Desktop. If you are unsure about your error statement, it can be helpful to copy and paste the error message into Google to learn more about your error.

Step 23. Before we continue, let's recap the goal of **Temperature_Predictions.R**.

The goal of the script is to use the December-January (DJ) MEI2 Index data to predict the average surface temperature anomaly for the upcoming year.

The last two lines of the **Console** shows two predictions that were calculated after running line #9 of the code. A description of both predictions is provided below:

- The first prediction is of the current year's average annual surface temperature anomaly based on the previous December-January (DJ) ENSO value from the MEI2 index. There is evidence that suggests the ENSO-DJ value relates to the upcoming average annual surface temperature anomaly.
    - For example, the December 2019/January 2020 ENSO value can help predict the 2020 average surface temperature anomaly.

- The second prediction is of the next year's average annual surface temperature anomaly based on the projected ENSO-DJ value.
    - For example, if the year is 2020, then the projected December 2020/January 2021 ENSO value is used to predict the average surface temperature anomaly for 2021.

Q5. The Console shows how the ENSO-DJ values can predict surface temperature anomalies for the current year and the next year. Fill in the blank spaces below with the year and the predicted values based on the information in the Console. (**Note:** The information in your Console will be different from the example above since the data is continuously updating).
Answers will vary depending on the year the activity is completed! These answers should be taken directly from the Console.

- Current year ____________ prediction (based on ENSO-DJ): ________ +/- ________ **˚C**

- Next Year ____________ prediction (based on projected ENSO-DJ): ________ +/- ________ **˚C**

Q6. The **+/-** symbol followed by a number in the prediction means that the predicted value can be within a specified range.

Answers will vary depending on the year the activity is completed!

For example, if the prediction was 2.11 +/- 0.5˚C, this means that the predicted value is likely to be somewhere between **1.61˚C** (the result from 2.11˚C – 0.5˚C) and **2.61˚C** (the result from 2.11˚C + 0.5˚C).

Using the example above as a guide, for each of the predictions provide the range of predicted values.

- Current year ____________ prediction range (based on ENSO-DJ): ______________________________

- Next Year ____________ prediction range (based on projected ENSO-DJ): ________________________

37. A plot should have also appeared in the lower right window of RStudio. Answer the following questions based on the predictions in the Console and the information in the plot.

Q7. Click on **Export** in the Plot window and choose **Copy to Clipboard**, as shown in the image below.

A new window will pop-up. Choose **Copy Plot** near the bottom right of the window. This will make a copy of your plot that can then be pasted into a document. Paste a copy of your plot in the blank space below.

Answers will vary depending on the year the activity is completed!

Q8. Based on the plot, describe the overall trend in annual average surface temperature anomalies from 1980 to present.

In general, from 1980 to present, the annual average surface temperature anomalies increased.

Q9. The plot shows the points representing the current year's and next year's surface temperature anomaly based on their previous ENSO-DJ index values. Based on the surface temperature anomaly values, during which year do you think the ENSO-DJ index was greater? Then, explain your answer.

Answers will vary depending on the year the activity is completed!

Year: ____________

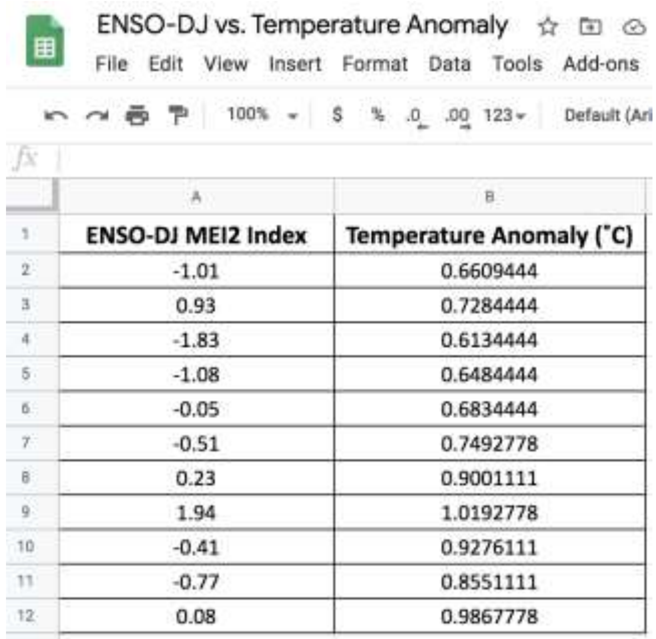
Explanation: ____

____

Step 38. The data table below contains the ENSO-DJ MEI2 Index and the average surface temperature anomaly from 2009 – 2019.

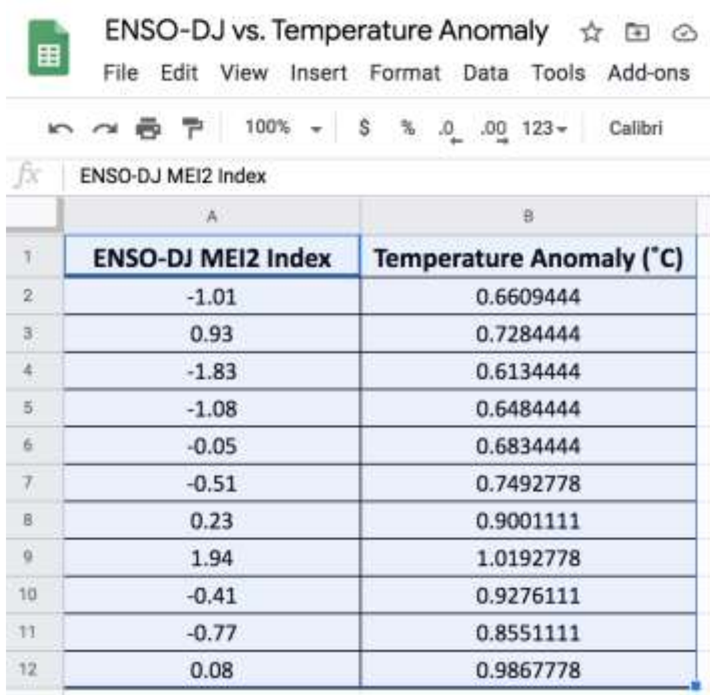
Year	ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
2009	-1.01	0.6609444
2010	0.93	0.7284444
2011	-1.83	0.6134444
2012	-1.08	0.6484444
2013	-0.05	0.6834444
2014	-0.51	0.7492778
2015	0.23	0.9001111
2016	1.94	1.0192778
2017	-0.41	0.9276111
2018	-0.77	0.8551111
2019	0.08	0.9867778

Copy and paste the **ENSO-DJ MEI2 Index** and **Temperature Anomaly** columns of the data table above into the first cell in a blank Google Sheets document, as shown in the image below.



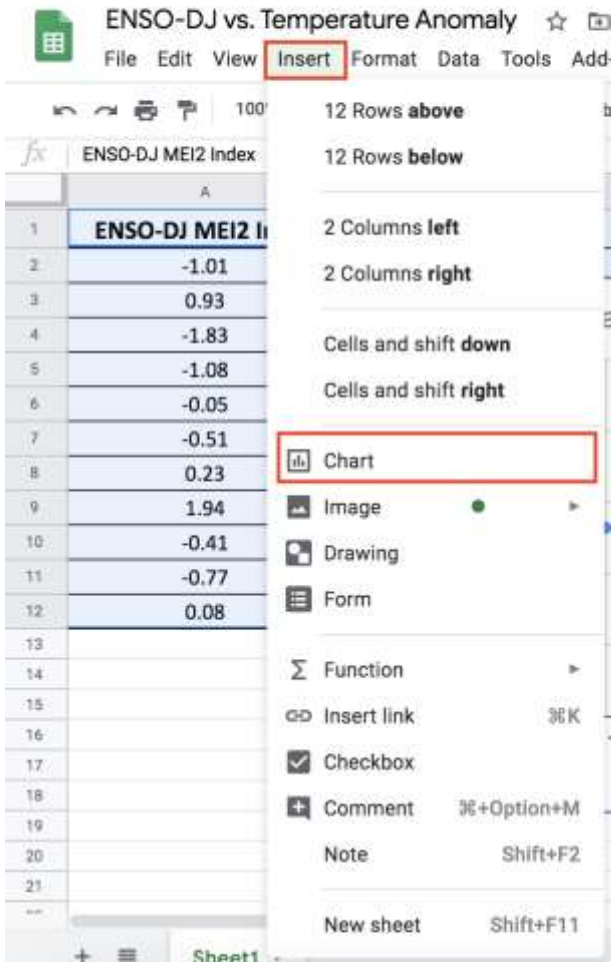
	ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
1	ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
2	-1.01	0.6609444
3	0.93	0.7284444
4	-1.83	0.6134444
5	-1.08	0.6484444
6	-0.05	0.6834444
7	-0.51	0.7492778
8	0.23	0.9001111
9	1.94	1.0192778
10	-0.41	0.9276111
11	-0.77	0.8551111
12	0.08	0.9867778

Step 39. Click on the first cell and drag to highlight all values as shown below.



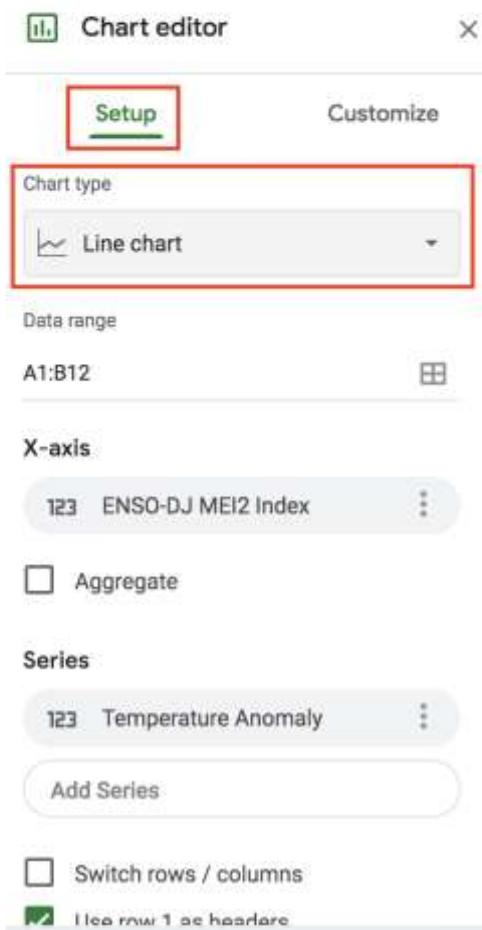
	ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
1	ENSO-DJ MEI2 Index	Temperature Anomaly (˚C)
2	-1.01	0.6609444
3	0.93	0.7284444
4	-1.83	0.6134444
5	-1.08	0.6484444
6	-0.05	0.6834444
7	-0.51	0.7492778
8	0.23	0.9001111
9	1.94	1.0192778
10	-0.41	0.9276111
11	-0.77	0.8551111
12	0.08	0.9867778

Then, click **Insert** near the top, and then click on **Chart**, as shown in the image below.



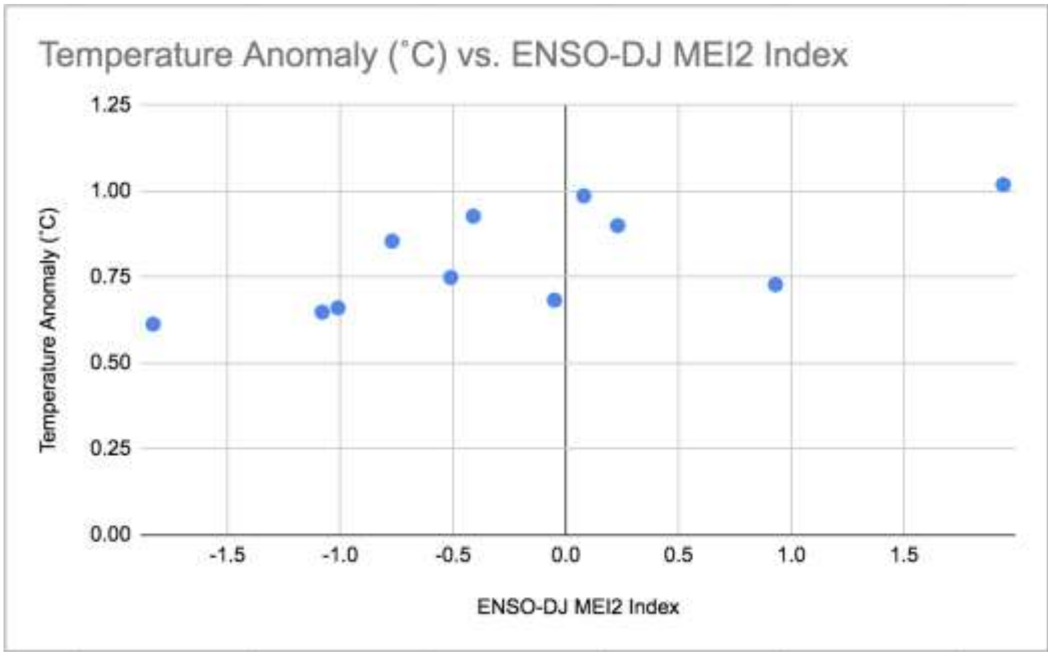
A chart will then be created, but we want to ensure the chart is a scatter plot. To do this, we need to use the Chart Editor, which should have appeared on the right side of Google Sheets.

At the top of the Chart Editor, click on **Setup**, and then **Chart type**, as shown in the image below.

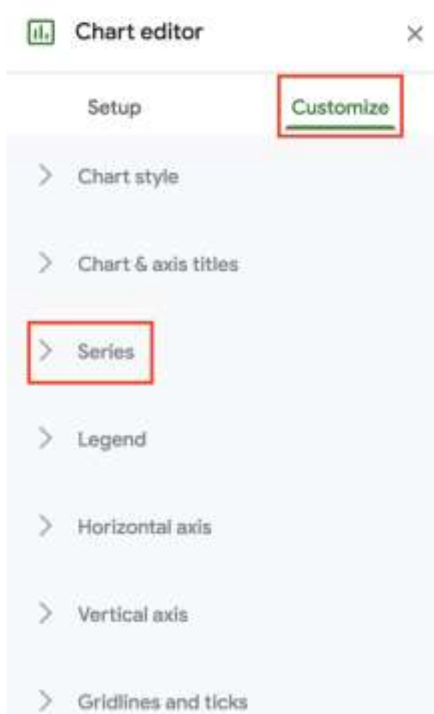


Look for the option that shows a scatter plot with all blue dots, as shown in the image below.

Your graph should now look like the following:

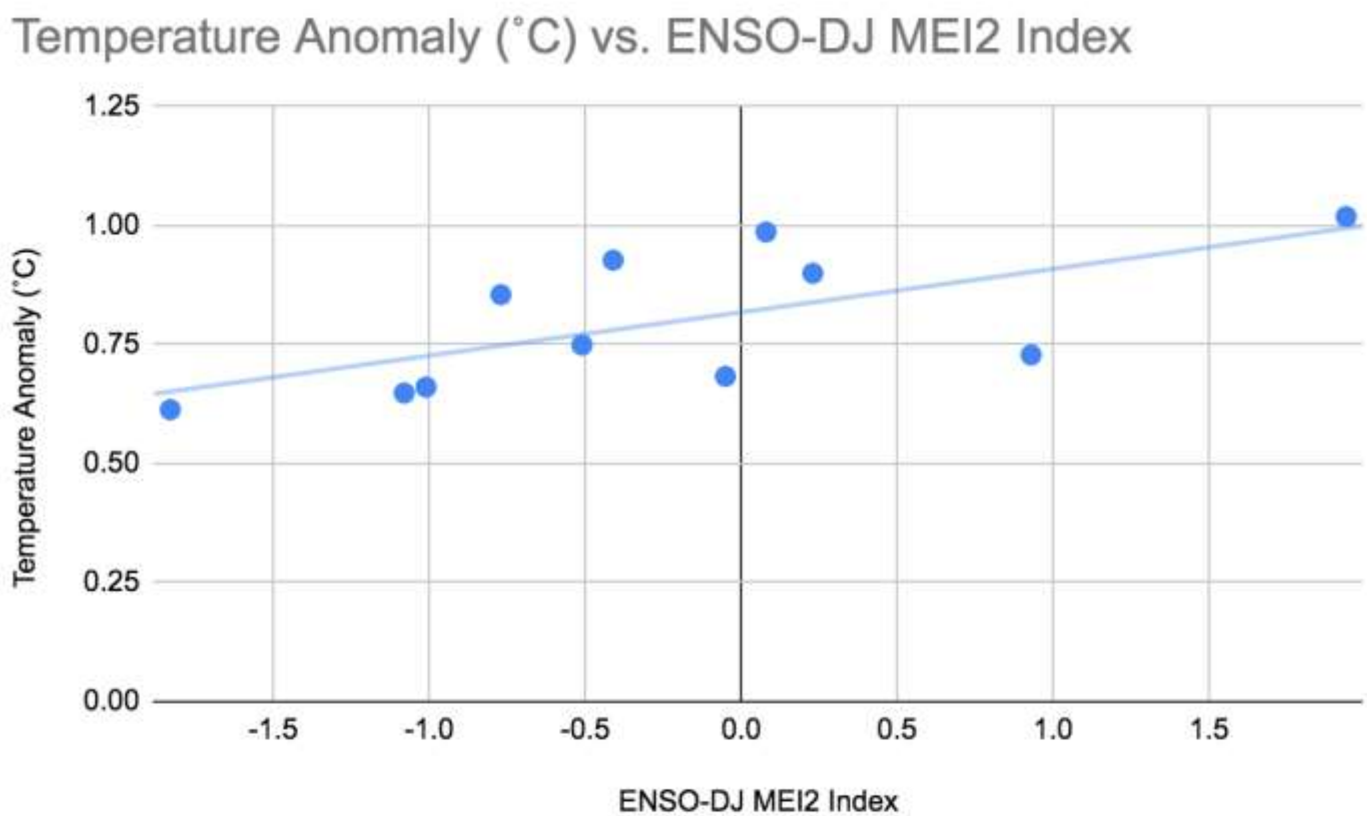


Step 40. On the top of the Chart Editor, click on Customize. Then, choose Series, as shown below.



Next, scroll down and check the box for Trendline.

Q10. Copy and paste the scatter plot you created into the blank space below.



Q11. Based on the scatter plot created in Google Sheets, what is the general relationship between the ENSO-DJ MEI2 Index and the temperature anomaly?

As the ENSO-DJ MEI2 Index increases, the temperature anomaly also increases.

Q12. Go back to the plot created in RStudio. Based on the predicted current and next year surface temperature anomaly values, choose one of the following. Then, justify your answer based on the relationship between the ENSO-DJ MEI2 Index and the temperature anomaly. In your justification, explain whether your prediction from Q9 was correct.

Answer depends on the year in which this activity is completed.

The current year ENSO-DJ is higher ***The next year ENSO-DJ is higher*** ***ENSO-DJ is the same (similar)***

For the justification, based on the ENSO-DJ and surface temperature anomaly relationship, a higher ENSO-DJ value is likely to lead to a higher surface temperature anomaly. On the other hand, a lower ENSO-DJ value is likely to lead to a lower surface temperature anomaly.

Q13. Go to [this link to access the MEI2 Index data.]() The first column contains the years 1979 to present, and the second column contains the ENSO-DJ values for each year.

In the data table, identify the two most recent years that contain an ENSO-DJ value, and then write the ENSO-DJ value for each year.

Answer depends on the year in which this activity is completed.

Year	ENSO-DJ

Based on the information in the data table, predict which year is likely to have a higher average temperature anomaly. Then, justify your answer.

Prediction: **Answer depends on the year in which this activity is completed.**

Justification: **For the justification, based on the ENSO-DJ and surface temperature anomaly relationship, a higher ENSO-DJ value is likely to lead to a higher surface temperature anomaly. On the other hand, a lower ENSO-DJ value is likely to lead to a lower surface temperature anomaly.**

EVALUATE

Base your answers to Q1 and Q2 on the content from the Engage, Explore, Explain, and Elaborate activities.

Q1. Explain why the El Niño Southern Oscillation (ENSO) and the Arctic Oscillation (AO) are referred to as teleconnections.

The El Niño Southern Oscillation (ENSO) and the Arctic Oscillation (AO) are considered to have teleconnections because these phenomena occur in one location on the Earth but can impact temperature and precipitation patterns worldwide.

Q2. If the Arctic Oscillation (AO) is in its negative phase during the first five months of 2021, predict how the climate of Siberia will be impacted. Your prediction should include changes to temperature, pressure, and environmental conditions related to wildfires.

If the Arctic Oscillation (AO) is in its negative phase, Siberia would be expected to have lower than normal air pressure, more precipitation, and a lower than normal surface temperature. This could reduce the threat to wildfires because the environment would be wetter and cooler as opposed to drier and warmer.

Q3. If the ENSO-DJ value of the MEI2 Index decreases this year to -0.55, predict how this change will impact the average global surface temperature anomaly in the next year. Then, justify your answer.

Prediction: **The average global surface temperature anomaly will decrease.**

Justification: **Based on the ENSO-DJ relationship, as the ENSO-DJ value decreases, it is likely that the global surface temperature anomaly will also decrease.**

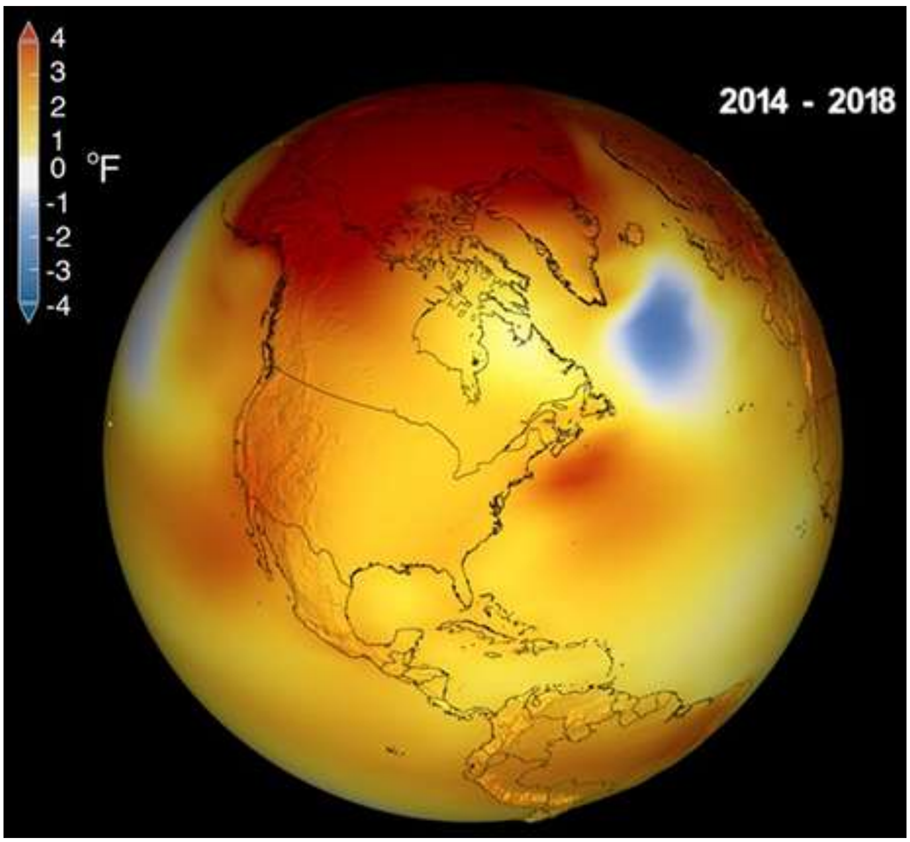
E. Conclusion and overview of linkages to next lesson and unit goals

In this lesson the students learned about atmospheric teleconnections and how the El Niño Southern Oscillation (ENSO) and the Arctic Oscillation (AO) can lead to changes in climate around the world. Specifically, the students learned what a teleconnection is through their knowledge of ENSO, and then learned about the Arctic Oscillation and its connection to wildfires in eastern Siberia. Towards the end of the lesson the students were able to utilize RStudio and an RScript created by NASA GISS scientists to analyze the relationship between the December/January ENSO phase and the current and next year's average global surface temperature anomaly. In the next lesson, the students will complete the final assessment activity by investigating one of two wildfire events and creating a presentation about the climate factors leading to the event.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Changes in Climate & Wildfires
Lesson #5 Title: Final Assessment Activity
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra N. LeGrande
NASA GSFC Office of Education – Code 160



XII. Lesson #5: Final Assessment Activity

A. Summary and Goals of Lesson

The goal of this lesson is to assess student knowledge of the entire unit through the Final Assessment Activity. In this lesson, the students will be given a partner and each pair will be assigned one of two wildfire events. The first event is the 2015 – 2016 Wildfires in the Southern Philippines and the second event is the Summer 2019 Wildfires in Alaska. Students will be given specific task items to complete and will utilize NASA's Panoply to investigate datasets used throughout the unit to uncover the climate factors leading to the wildfires. Students will also use NASA's Fire Information Resource Management System (FIRMS) to visualize the extent of the wildfires during their event. The students will then create a presentation to teach their partner about the climate factors influencing their event.

B. Table of Contents for lesson

C. Lesson Template

Final Assessment Lesson Plan – Earth Science

Unit: Changes in Climate & Wildfires **Topic**: Final Assessment Activity

Anchor Phenomenon:

The amount and intensity of wildfires has been increasing.

Aim: Why do wildfires occur in different regions across the Earth?

Next Generation Science Standards (NGSS):

Performance Expectation:

- **HS-ESS2-2**. – Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to Earth's systems.
  - **Science and Engineering Practices:**
    - Analyzing and Interpreting Data
  - **Disciplinary Core Ideas**:
    - ESS2.D: Weather and Climate
  - **Cross-cutting Concepts:**
    - Stability and Change

Performance Expectation:

- **HS-ESS2-4.** – Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate
  - **Science and Engineering Practices:**
    - Analyzing and Interpreting Data
  - **Disciplinary Core Ideas**:
    - ESS2.D: Weather and Climate
  - **Cross-cutting Concepts:**
    - Cause and Effect

Performance Expectation:

- **HS-ESS3-5** – Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems
  - **Science and Engineering Practices:**
    - Analyzing and Interpreting Data
  - **Disciplinary Core Ideas**:
    - ESS2.D: Weather and Climate
    - ESS3.D: Global Climate Change
  - **Cross-cutting Concepts:**
    - Stability and Change

Multiple Science Domains:
This lesson contains links between the Earth and Space Science DCIs listed above and the following Physical Science DCIs:

- PS3.B Conversion of Energy and Energy Transfer
- PS4.B Electromagnetic Radiation

Common Core Learning Standards (CCLS):

- **11-12.RST.3** - Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

- **11-12.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

- **11-12.RST.9** - Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Performance Objective: Students will be able to make connections between changes in climate and wildfires by creating a presentation that evaluates how changes in climate in the southern Philippines or Alaska led to an increase in wildfires.

Materials:

- Class set of computers
- ssta.nc, precip.nc, precip_ltm.nc, and TempAnomaly.nc datasets
- NASA Panoply software
- Google Slides or similar platform

Links to electronic resources are provided below:

- Link to NASA FIRMS

Vocabulary:

No new vocabulary.

Development of the Lesson: Four and a half-day lesson (4.5 class periods)

What the teacher does	What the student does	Time
1. Assign students into heterogeneous pairs (varying academic levels) and then assign each student Event #1(wildfires in southern Philippines) or Event #2 (wildfires in Alaska).	The students read the activity description based on the task they were assigned. The students review the rubric for the activity and ask questions about how they will be assessed.	**½ period**

What the teacher does	What the student does	Time
• Assessment activity can be differentiated by assigning stronger students Event #1, which requires applications to ENSO. Have the students read through Tasks 1 – 3 and the activity rubric. Review the rubric with the students and answer any questions.		
2. Circulate as the students work on their event Tasks #1 and #2 and answer Q1 to Q4. • Make sure the students are correctly combining the precip.nc and precip_ltm.nc datasets in Panoply, and that the anomaly calculation is correct • Check in with Event #1 students to ensure they are correctly identifying the ENSO phase • Check in with Event #2 students to ensure they are correctly making connections between albedo and surface temperature. ***Assessment Opportunity #1 (Student answers to Q1 to Q4)***	The students use the climate datasets and Panoply to complete Tasks #1 and #2. The students answer Q1 to Q4 based on the maps they create in Panoply.	**1.5 periods**
3. Circulate as the students begin Task #3 and begin creating their presentations in Google Slides. • Check in with the students to ensure they know how to use FIRMS and include the wildfire maps in their presentation. • Remind students to use the rubric to guide their presentation.	The students work on Task #3 and create a presentation in Google Slides based on the climate factors influencing the wildfires in their location.	**1.5 periods**
4. Have the students present their work to their partner. • Explain to the students how they will be giving peer feedback using the Glow & Grow protocol. ***Assessment Opportunity #2 (Student-created presentations)***	The students present their work to their partner. The students provide peer feedback using the Glow & Grow protocol. After the presentations, each student evaluates the peer feedback.	**1 period**

<u>Summary/Conclusion</u>: The students present their work to their partner and provide peer feedback using the Glow & Grow protocol. After the presentations, each student evaluates the peer feedback.

Differentiated Instruction:

- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- The Final Assessment Activity can be differentiated based on student academic level. Event #1 can be assigned to higher-level students since the applications to ENSO are more challenging.
- Students who need extra support can join the teacher for small group instruction and more efficient feedback.
- All images and graphs have alternative text.

Notes For Revision:

D. Supporting Documents (order according to sequence of lesson)

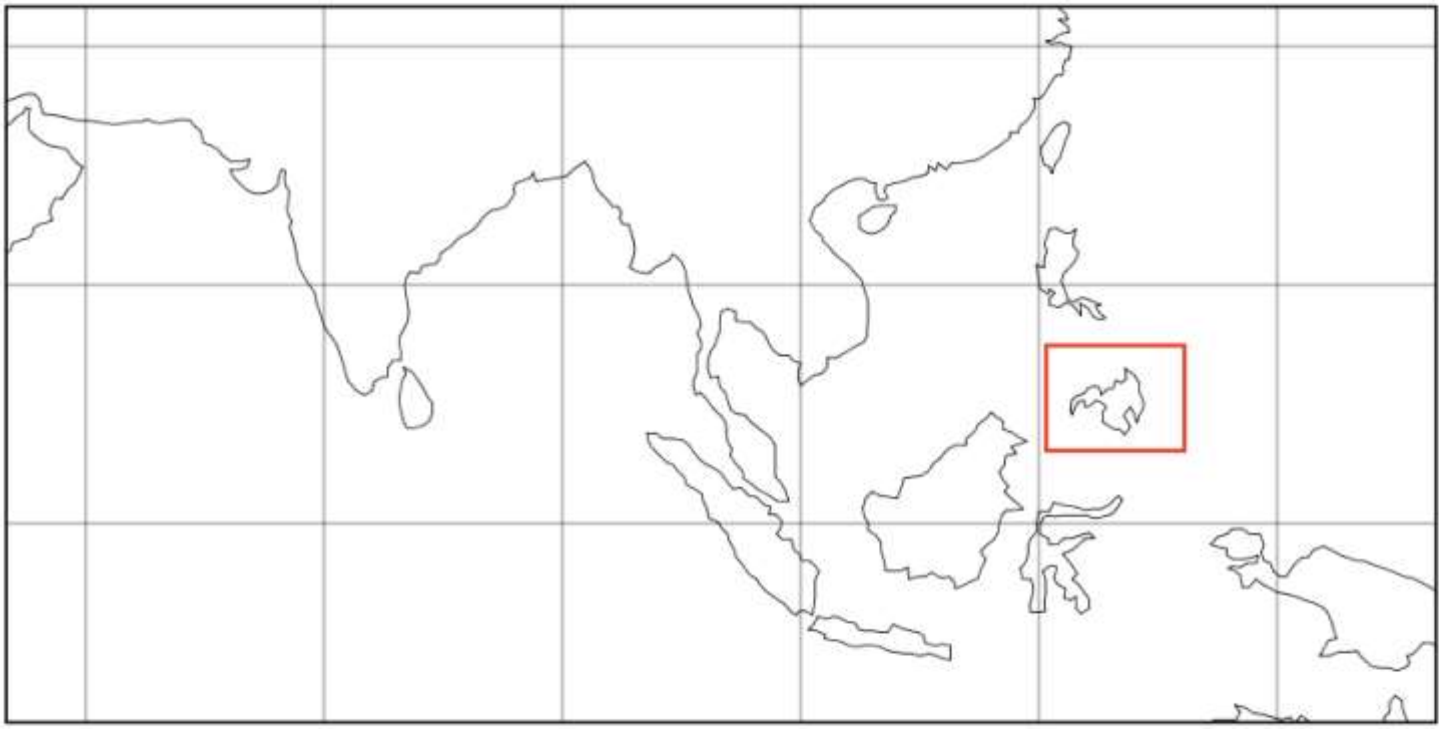
Final Assessment Activity

Anchor Phenomenon – *The amount and intensity of wildfires has been increasing.*

Directions: Students will be working in pairs. Each student will choose one of the two wildfire events below and complete the tasks based on the knowledge gained and resources from Lessons #1, #2, and #3 to evaluate the climate factors influencing the wildfires.

Event #1: 2015 – 2016 Wildfires in the Southern Philippines

The southern Philippines experienced an increase in wildfires at the end of 2015 and beginning of 2016. The area of interest is outlined in the images below. The first image is from Google Maps and the second image is from a map in Panoply centered on 10˚N latitude and 100˚E longitude.



Task 1. Refer to the EXPLORE #2 activity in Lesson #1 for guidance, if needed. Using the **precip.nc** and **precip_ltm.nc** datasets, create precipitation anomaly maps in Panoply for October 2015 to April 2016 based on the following criteria:

- The array subtraction in Panoply consists of ***precip.nc – precip_ltm.nc***
- The color table is **CB_BrBG.cpt**
- The min and max scale range is **-8** and **8** and major divisions is **4**.
- The map projection is Equirectangular (Regional)
- The map is centered on 100˚E longitude and 10˚N latitude
- When changing the time slice number for the ***precip.nc and precip_ltm.nc*** arrays, make sure the month for ***precip_ltm.nc*** corresponds to the month for ***precip.nc***. For example, when analyzing the precipitation anomaly in January 2016, the ***precip.nc*** array needs to be set to January 2016 while the ***precip_ltm.nc*** array needs to be set to 1, representing the January average. This is shown in the image below.

For another example, when you change the month to October 2015, be sure to change the other array to 10 for October.

Q1. In general, describe the precipitation anomalies in the southern Philippines between October 2015 and April 2016.

____

____

Task 2. Refer to the EXPLORE #1 activity in Lesson #1 for guidance, if needed. Using the **ssta.nc** dataset, create sea surface temperature anomaly maps in Panoply for October 2015 to April 2016 based on the following criteria:

- The color table is **CB_RdBu.cpt**
- Check off the box below the color table for **Reverse Colors**
- The min and max scale range is **-3** and **3** and major divisions is **6**.
- The map is centered on -150˚E longitude (150˚W) and 0˚N latitude

Q2. In general, describe the sea surface temperature anomalies in the eastern equatorial Pacific Ocean between October 2015 and April 2016.

____

____

Q3. Identify whether the phase of ENSO between October 2015 and April 2016 is El Niño (ENSO positive), La Niña (ENSO negative), or Neutral. Then, justify your answer based on the sea surface temperature anomalies in the eastern equatorial Pacific Ocean and your knowledge of the development of ENSO phases.

ENSO Phase: ____

Justification: ____

____

Q4. Based on the ENSO phase and precipitation anomalies between October 2015 and April 2016, explain why the southern Philippines experienced widespread wildfires during this time period. Your answer should include the following:

- How and why the ENSO phase impacts air pressure in the region
- How and why the ENSO phase impacts precipitation in the region
- How environmental conditions conducive to wildfires developed as a result of the ENSO phase

____

____

____

____

Task 3. Using Google Slides or a similar platform, create a presentation to teach your partner about the climate factors related to the wildfires in the southern Philippines between October 2015 and April 2016. The rubric that will be used to evaluate each presentation is found on the last page of the activity. Your presentation should include the following components:

- **Background:** Describe the location in terms of geographic information and a general description of the location's climate.
  - Incorporating maps and images is highly encouraged!

- **Climate Factors:** Describe how and why the climate of the location was impacted between October 2015 and April 2016 based on the data from Tasks 1 and 2.
  - Use the information from Q1 to Q4 to help you.
  - At least one Panoply map each from Task 1 and Task 2 should be included in your slides.

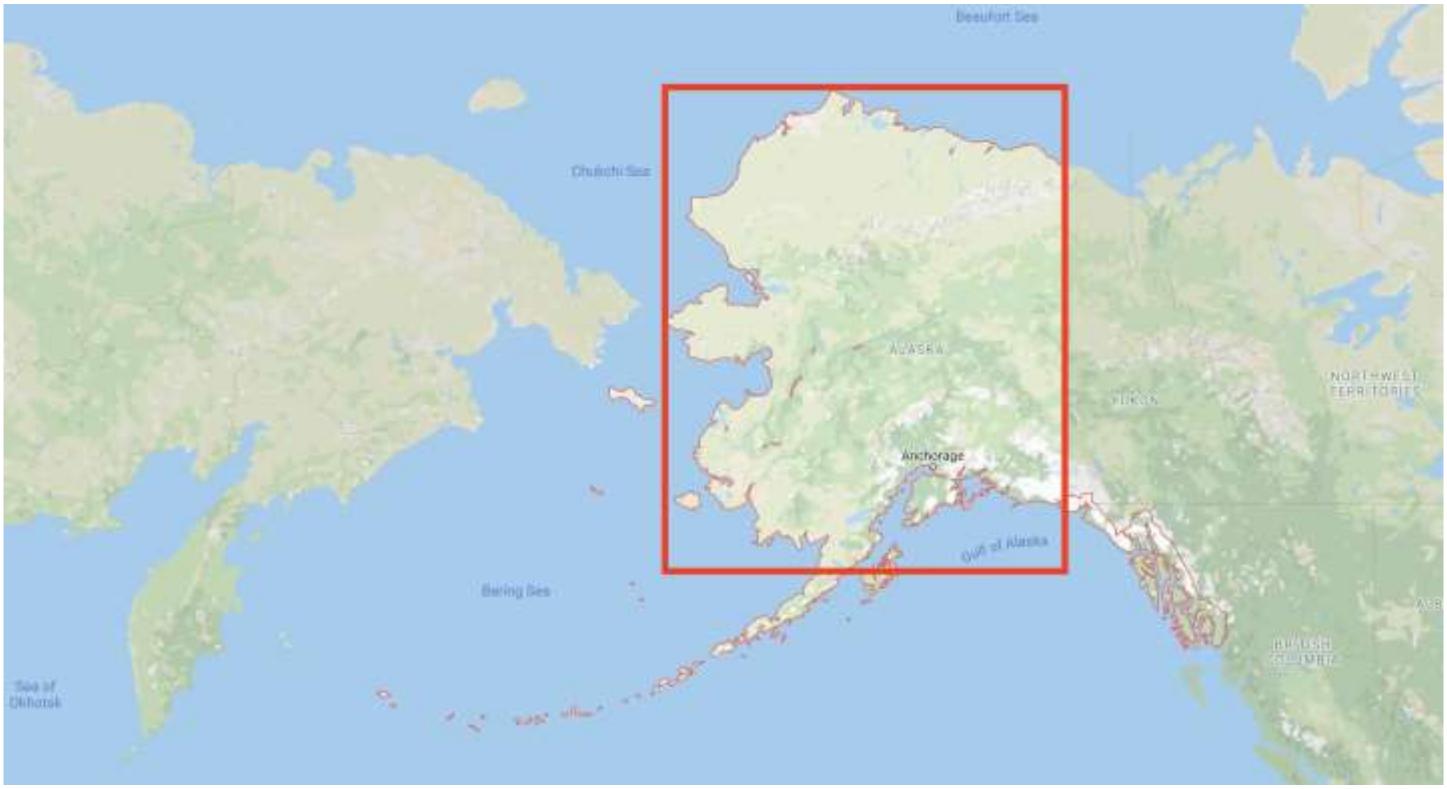
- **Explanation:** Explain why the change in climate conditions led to wildfires based on the information learned from all lessons. You should also include information from FIRMS, a NASA-based system that shows the locations of wildfires. With this source you can show how the number of wildfires between October 2015 and April 2016 was greater compared to the same months in earlier and later years. Below is a description of how to use FIRMS.
  1. Go to [this link to access FIRMS] and locate the southern Philippines.
  2. ***The following is an example and can be applied to any date.*** Using the window on the right side of the screen, click on the **Advanced** tab. Next, click on the calendar to change the date to **February 1, 2017**. Then, click on "**1 day**" and change that to "**4 weeks**". Finally, only check the box that states **VIIRS 375m/Suomi NPP**. The window should now look like the following:

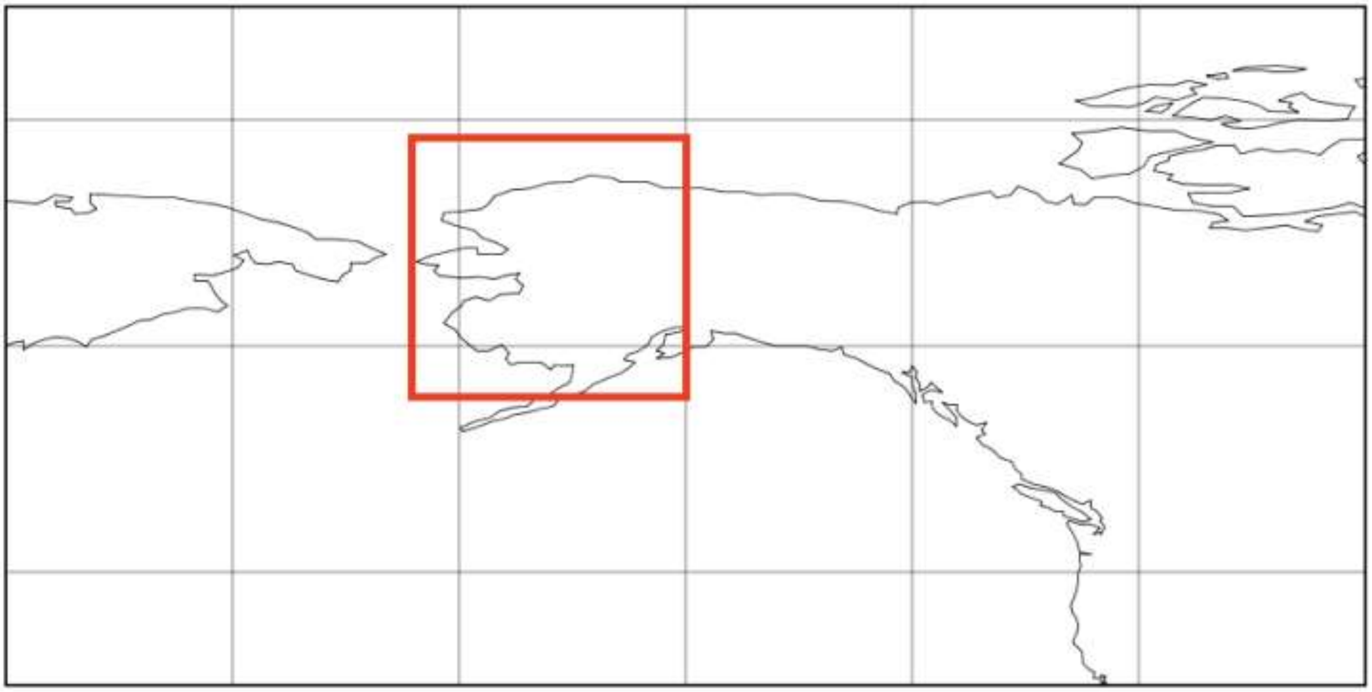
3. Use FIRMS to create three maps that shows how the number of wildfires has changed based on the following time constraints:
    a. One map **during** the month & year of the specified time period
    b. One map exactly **one year before** the month & year of the specified time period
    c. One map exactly **one year after** the month & year of the specified time period

4. Take a screenshot of each map and include them in your presentation to emphasize how environmental conditions led to wildfires during the specified time period.

Event #2: Summer 2019 Wildfires in Alaska

During the Summer 2019, Alaska experienced an extreme fire season that resulted in widespread wildfires. The area of interest is outlined in the images below. The first image is from Google Maps and the second image is from a map in Panoply centered on 60˚N latitude and 150˚W longitude.





Task 1. Refer to the EXPLORE activity in Lesson #3 for guidance, if needed. Using the **TempAnomaly.nc** dataset, create surface temperature anomaly maps in Panoply for the Summer 2019 based on the following criteria:

- The color table is **CB_RdBu.cpt**
- Check off the box below the color table for **Reverse Colors**
- The min and max scale range is **-3** and **3** and major divisions is **6**.
- The map projection is Equirectangular (Regional)
- The map is centered on -150˚E (150˚W) longitude and 60˚N latitude

Q1. In general, describe the surface temperature anomalies in Alaska during the Summer 2019.

____

____

Q2. Explain how the change in albedo of the Alaskan surface could have contributed to the temperature anomalies described in Q1.

____

____

____

Task 2. Refer to the EXPLORE #2 activity in Lesson #1 for guidance, if needed. Using the **precip.nc** and **precip_ltm.nc** datasets, create precipitation anomaly maps in Panoply for the Summer 2019 based on the following criteria:

- The array subtraction in Panoply consists of ***precip.nc – precip_ltm.nc***
- The color table is **CB_BrBG.cpt**
- The min and max scale range is **-3** and **3** and major divisions is **6**.
- The map projection is Equirectangular (Regional)
- The map is centered on -150˚E longitude and 60˚N latitude
- When changing the time slice number for the ***precip.nc and precip_ltm.nc*** arrays, make sure the month for ***precip_ltm.nc*** corresponds to the month for ***precip.nc***. For example, when analyzing the precipitation anomaly in June 2019, the ***precip.nc*** array needs to be set to June 2019 while the ***precip_ltm.nc*** array needs to be set to 6, representing the June average. This is shown in the image below.

For another example, when you change the month to July 2019, be sure to change the other array to 7 for July.

Q3. In general, describe the precipitation anomalies in Alaska during the Summer 2019.

Q4. Based on the information from Q1 to Q3 regarding the changes in climate in Alaska during the Summer 2019, explain why Alaska experienced widespread wildfires during this time period. Your answer should include the following:

- How and why albedo impacted the surface temperature anomalies
- How the surface temperature anomalies impacted precipitation in the region
- How environmental conditions conducive to wildfires developed

Task 3. Using Google Slides or a similar platform, create a presentation to teach your partner about the climate factors related to the wildfires in Alaska during the Summer 2019. The rubric that will be used to evaluate each presentation is found on the last page of the activity. Your presentation should include the following components:

- **Background:** Describe the location in terms of geographic information and a general description of the location's climate.
    - Incorporating maps and images is highly encouraged!

- **Climate Factors:** Describe how and why the climate of the location was impacted during the Summer 2019 based on the data from Tasks 1 and 2.
    - Use the information from Q1 to Q4 to help you.
    - At least one Panoply map each from Task 1 and Task 2 should be included in your slides.

- **Explanation:** Explain why the change in climate conditions led to wildfires based on the information learned from all lessons. You should also include information from FIRMS, a NASA-based system that shows the locations of wildfires. With this source you can show how the number of wildfires during the Summer 2019 was greater compared to the same months in earlier and later years. Below is a description of how to use FIRMS.
    1. Go to [this link to access FIRMS]() and locate Alaska.
    2. ***The following is an example and can be applied to any date.*** Using the window on the right side of the screen, click on the **Advanced** tab. Next, click on the calendar to change the date to **February 1, 2017**. Then, click on "**1 day**" and change that to "**4 weeks**". Finally, only check the box that states **VIIRS 375m/Suomi NPP**. The window should now look like the following:

    3. Use FIRMS to create three maps that shows how the number of wildfires has changed based on the following time constraints:
        a. One map **during** the month & year of the specified time period

b. One map exactly **one year before** the month & year of the specified time period
c. One map exactly **one year after** the month & year of the specified time period

4. Take a screenshot of each map and include them in your presentation to emphasize how environmental conditions led to wildfires during the specified time period.

Final Assessment Activity – Oral Presentation Peer Feedback

Directions: For each presentation, provide one glow and one grow. A glow is a statement that tells your partner what they did well, something you thoroughly enjoyed, etc. A grow is a statement that tells your partner what could be improved, and a suggestion on how to improve it.

Helpful tip: Your feedback should be helpful and not judgmental.

Event: ____

Glow: ____

____

Grow: ____

____

Climate & Wildfires – Presentation Rubric

CATEGORY	4	3	2	1
Background	Student fully and accurately explains the geography and general climate of their location, including images to accompany the description.	Student accurately describes the geography and general climate of their location, but more detail could have been provided.	Student makes one error when describing the geography and general climate of their location.	Student makes more than one error when describing the geography and general climate of their location.
Climate Factors	Student fully explains the factors that influenced the changes in climate for their location during the specified time period.	Student explains the factors that influenced the changes in climate for their location during the specified time period, but more detail could have been provided for seasonal changes.	Student makes one error when describing the factors that influenced the changes in climate for their location during the specified time period OR does not include one piece of required information.	Student makes more than one error when describing the factors that influenced the changes in climate for their location during the specified time period OR does not include more than one piece of required information.
Explanation	Student fully explains how the change in climate conditions led to wildfires based on content from Lessons #1 - #3.	Student explains how the change in climate conditions led to wildfires based on content from Lessons #1 - #3, but more detail could have been provided.	Student makes one error when describing how the change in climate conditions led to wildfires based on content from Lessons #1 - #3.	Student makes more than one error when describing how the change in climate conditions led to wildfires based on content from Lessons #1 - #3.
Maps & Images	Student includes at least two maps related to changes in climate and at least three maps showing wildfires in FIRMS. All maps and images are accurate.	Student includes at least two maps related to changes in climate and at least three maps showing wildfires in FIRMS. There is one error in the maps or images.	Student includes at least two maps related to changes in climate and at least three maps showing wildfires in FIRMS. There is more than one error in the maps or images.	Student is missing one or more required map or image.
Appearance of Slides	All slides have a main font text and a color scheme that can be read by all audience members. All slides have text that is concise and easy to follow.	One slide does not have a main font text and a color scheme that can be read by all audience members. One slide does not have text that is concise and easy to follow.	Two slides do not have a main font text and a color scheme that can be read by all audience members. Two slides do not have text that is concise and easy to follow.	More than two slides do not have a main font text and a color scheme that can be read by all audience members. More than two slides do not have text that is concise and easy to follow.

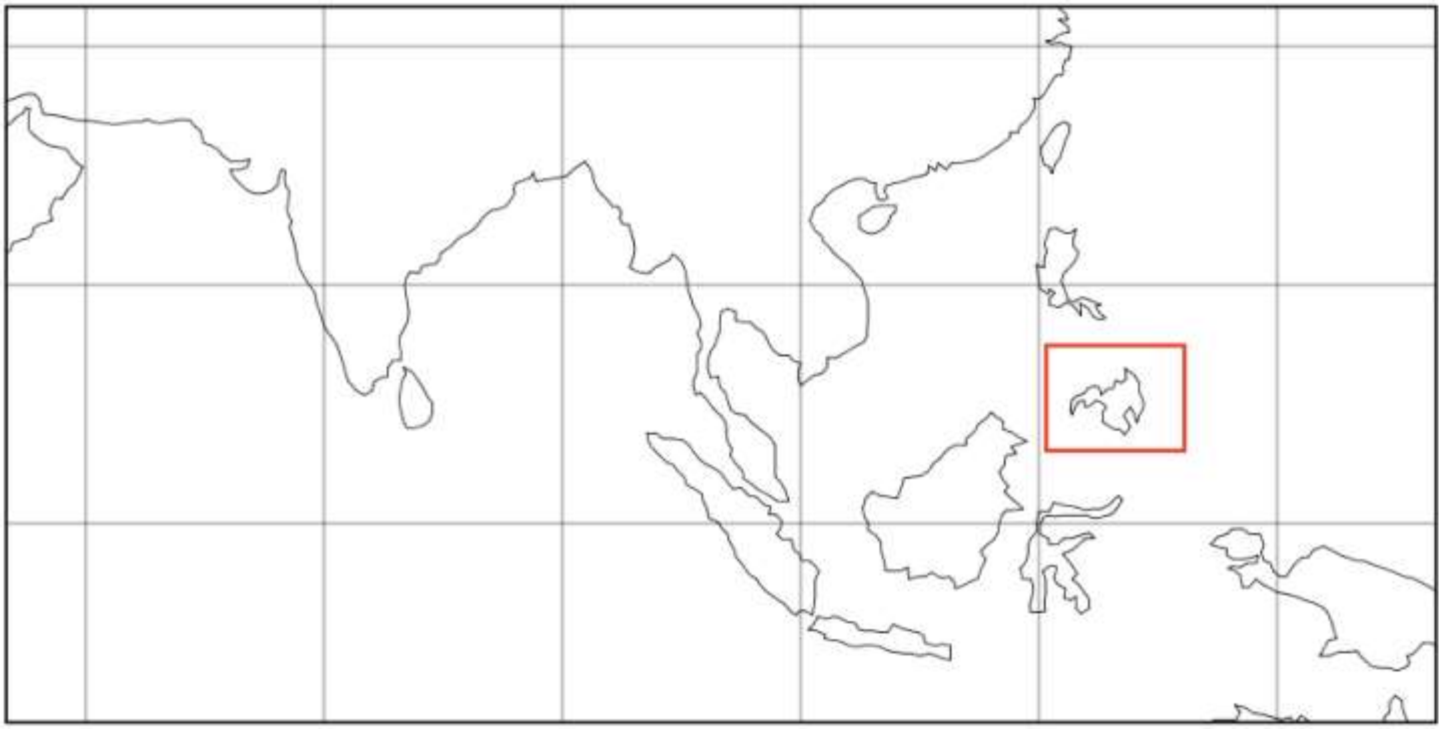
Final Assessment Activity - Answers

Anchor Phenomenon – *The amount and intensity of wildfires has been increasing.*

Directions: Students will be working in pairs. Each student will choose one of the two wildfire events below and complete the tasks based on the knowledge gained and resources from Lessons #1, #2, and #3 to evaluate the climate factors influencing the wildfires.

Event #1: 2015 – 2016 Wildfires in the Southern Philippines

The southern Philippines experienced an increase in wildfires at the end of 2015 and beginning of 2016. The area of interest is outlined in the images below. The first image is from Google Maps and the second image is from a map in Panoply centered on 10˚N latitude and 100˚E longitude.



Task 1. Refer to the EXPLORE #2 activity in Lesson #1 for guidance, if needed. Using the **precip.nc** and **precip_ltm.nc** datasets, create precipitation anomaly maps in Panoply for October 2015 to April 2016 based on the following criteria:

- The array subtraction in Panoply consists of ***precip.nc – precip_ltm.nc***
- The color table is **CB_BrBG.cpt**
- The min and max scale range is **-8** and **8** and major divisions is **4**.
- The map projection is Equirectangular (Regional)
- The map is centered on 100˚E longitude and 10˚N latitude
- When changing the time slice number for the ***precip.nc and precip_ltm.nc*** arrays, make sure the month for ***precip_ltm.nc*** corresponds to the month for ***precip.nc***. For example, when analyzing the precipitation anomaly in January 2016, the ***precip.nc*** array needs to be set to January 2016 while the ***precip_ltm.nc*** array needs to be set to 1, representing the January average. This is shown in the image below.

For another example, when you change the month to October 2015, be sure to change the other array to 10 for October.

Q1. In general, describe the precipitation anomalies in the southern Philippines between October 2015 and April 2016.

In general, the precipitation anomalies in the southern Philippines were negative, indicating below average precipitation.

Task 2. Refer to the EXPLORE #1 activity in Lesson #1 for guidance, if needed. Using the **ssta.nc** dataset, create sea surface temperature anomaly maps in Panoply for October 2015 to April 2016 based on the following criteria:

- The color table is **CB_RdBu.cpt**
- Check off the box below the color table for **Reverse Colors**
- The min and max scale range is **-3** and **3** and major divisions is **6**.
- The map is centered on -150˚E longitude (150˚W) and 0˚N latitude

Q2. In general, describe the sea surface temperature anomalies in the eastern equatorial Pacific Ocean between October 2015 and April 2016.

In general, the sea surface temperature anomalies in the eastern equatorial Pacific Ocean were positive, indicating above average sea surface temperature.

Q3. Identify whether the phase of ENSO between October 2015 and April 2016 is El Niño (ENSO positive), La Niña (ENSO negative), or Neutral. Then, justify your answer based on the sea surface temperature anomalies in the eastern equatorial Pacific Ocean and your knowledge of the development of ENSO phases.

ENSO Phase: **El Niño (ENSO positive)**

Justification: **During El Niño (ENSO positive) phase, the easterly trade winds are weaker, allowing for the buildup of warmer sea surface temperature in this area. There was an El Niño event because the sea surface temperature anomalies were significantly higher than average (El Niño events are classified when sea surface temperature anomalies in the central equatorial Pacific Ocean are 0.5˚C or greater).**

Q4. Based on the ENSO phase and precipitation anomalies between October 2015 and April 2016, explain why the southern Philippines experienced widespread wildfires during this time period. Your answer should include the following:

- How and why the ENSO phase impacts air pressure in the region
- How and why the ENSO phase impacts precipitation in the region
- How environmental conditions conducive to wildfires developed as a result of the ENSO phase

There was an El Niño event during the time period characterized by an increase in sea surface temperature anomalies in the eastern equatorial Pacific Ocean. This led to lower pressure in the eastern equatorial Pacific Ocean and higher pressure in the western equatorial Pacific Ocean, near the southern Philippines. The higher pressure reduced cloud formation and therefore precipitation. The drought and dry conditions in the southern Philippines increased the chances of wildfires to develop and spread.

An alternate explanation is the area of maximum rainfall in the tropical Pacific follows the area of maximum sea surface temperature. During El Nino positive phase, this warm ocean area moves to the east of the Philippines, also bringing the area of greater rainfall to the east of the Philippines. This leaves the Philippines with decreased rainfall and drought conditions.

Task 3. Using Google Slides or a similar platform, create a presentation to teach your partner about the climate factors related to the wildfires in the southern Philippines between October 2015 and April 2016. The rubric that will be used to evaluate each presentation is found on the last page of the activity. Your presentation should include the following components:

- **Background:** Describe the location in terms of geographic information and a general description of the location's climate.
  - Incorporating maps and images is highly encouraged!

- **Climate Factors:** Describe how and why the climate of the location was impacted between October 2015 and April 2016 based on the data from Tasks 1 and 2.
  - Use the information from Q1 to Q4 to help you.
  - At least one Panoply map each from Task 1 and Task 2 should be included in your slides.

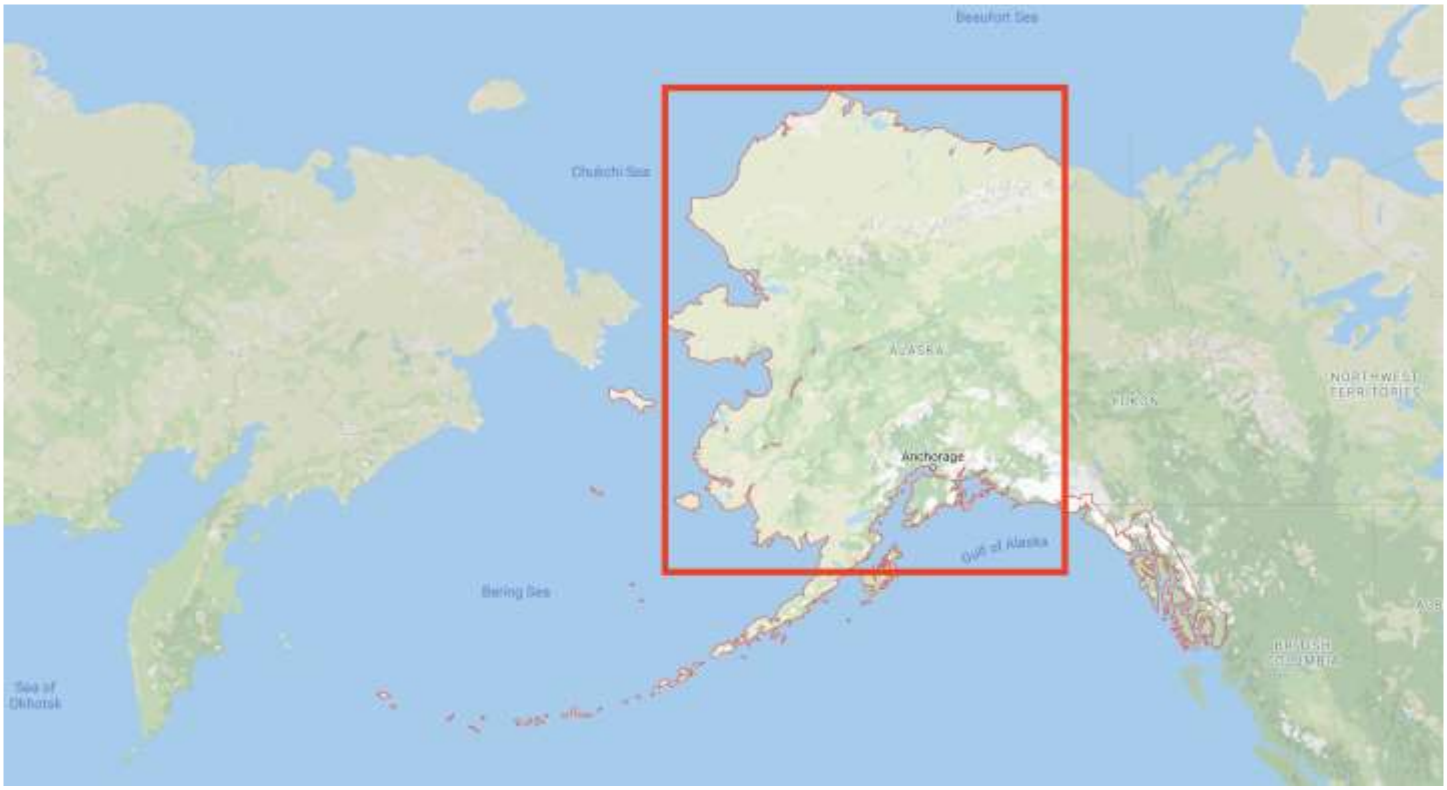
- **Explanation:** Explain why the change in climate conditions led to wildfires based on the information learned from all lessons. You should also include information from FIRMS, a NASA-based system that shows the locations of wildfires. With this source you can show how the number of wildfires between October 2015 and April 2016 was greater compared to the same months in earlier and later years. Below is a description of how to use FIRMS.
  1. Go to [this link to access FIRMS] and locate the southern Philippines.
  2. ***The following is an example and can be applied to any date.*** Using the window on the right side of the screen, click on the **Advanced** tab. Next, click on the calendar to change the date to **February 1, 2017**. Then, click on "**1 day**" and change that to "**4 weeks**". Finally, only check the box that states **VIIRS 375m/Suomi NPP**. The window should now look like the following:

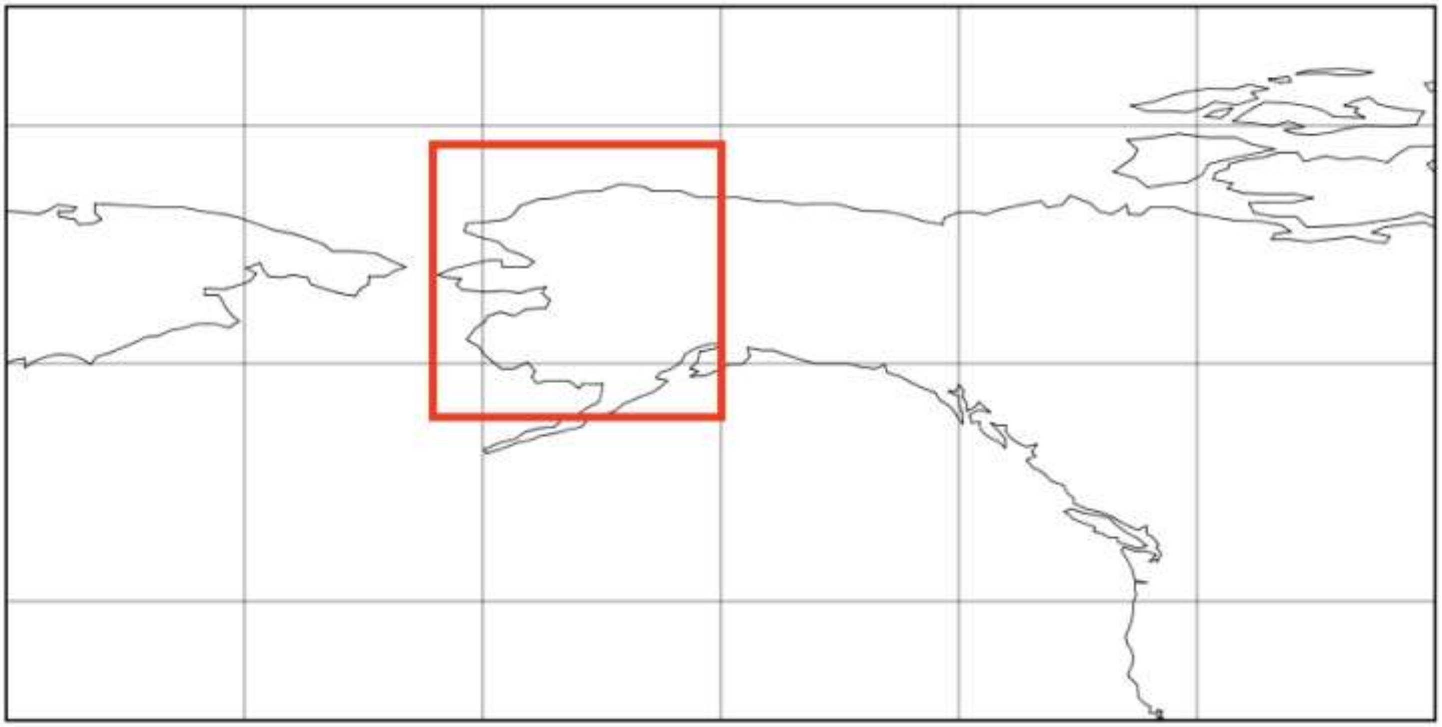
3. Use FIRMS to create three maps that show how the number of wildfires has changed based on the following time constraints:
    a. One map **during** the month & year of the specified time period
    b. One map exactly **one year before** the month & year of the specified time period
    c. One map exactly **one year after** the month & year of the specified time period

4. Take a screenshot of each map and include them in your presentation to emphasize how environmental conditions led to wildfires during the specified time period.

Event #2: Summer 2019 Wildfires in Alaska

During the Summer 2019, Alaska experienced an extreme fire season that resulted in widespread wildfires. The area of interest is outlined in the images below. The first image is from Google Maps and the second image is from a map in Panoply centered on 60˚N latitude and 150˚W longitude.





Task 1. Refer to the EXPLORE activity in Lesson #3 for guidance, if needed. Using the **TempAnomaly.nc** dataset, create surface temperature anomaly maps in Panoply for the Summer 2019 based on the following criteria:

- The color table is **CB_RdBu.cpt**
- Check off the box below the color table for **Reverse Colors**
- The min and max scale range is **-3** and **3** and major divisions is **6**.
- The map projection is Equirectangular (Regional)
- The map is centered on -150˚E (150˚W) longitude and 60˚N latitude

Q1. In general, describe the surface air temperature anomalies in Alaska during the Summer 2019.

In general, the surface air temperature anomalies in Alaska during the Summer 2019 are positive, indicating warmer than average temperature during this time compared to the average base period of 1950 – 1980.

Q2. Explain how the change in albedo of the Alaskan surface could have contributed to the temperature anomalies described in Q1.

Albedo is a measure of how reflective a surface is. A higher albedo means a greater amount of energy is reflected. Snow and ice have high albedo, while surfaces like the ocean and vegetation have low albedo. As temperatures increase, the snow and ice in Alaska continues to melt, revealing the underlying surface, thus yielding lower albedo. Lower albedo allows for a greater absorption of energy, which increases temperature even more.

Task 2. Refer to the EXPLORE #2 activity in Lesson #1 for guidance, if needed. Using the **precip.nc** and **precip_ltm.nc** datasets, create precipitation anomaly maps in Panoply for the Summer 2019 based on the following criteria:

- The array subtraction in Panoply consists of ***precip.nc – precip_ltm.nc***
- The color table is **CB_BrBG.cpt**
- The min and max scale range is **-3** and **3** and major divisions is **6**.
- The map projection is Equirectangular (Regional)
- The map is centered on -150˚E longitude and 60˚N latitude
- When changing the time slice number for the ***precip.nc and precip_ltm.nc*** arrays, make sure the month for ***precip_ltm.nc*** corresponds to the month for ***precip.nc***. For example, when analyzing the precipitation anomaly in June 2019, the ***precip.nc*** array needs to be set to June 2019 while the ***precip_ltm.nc*** array needs to be set to 6, representing the June average. This is shown in the image below.

For another example, when you change the month to July 2019, be sure to change the other array to 7 for July.

Q3. In general, describe the precipitation anomalies in Alaska during the Summer 2019.

In general, the precipitation anomalies in Alaska during the Summer 2019 were negative, indicating below average precipitation where the amount of precipitation is less during the summer of 2019 compared to the base period of 1981-2010.

Q4. Based on the information from Q1 to Q3 regarding the changes in climate in Alaska during the Summer 2019, explain why Alaska experienced widespread wildfires during this time period. Your answer should include the following:

- How and why albedo impacted the surface temperature anomalies
- How the surface temperature anomalies impacted precipitation in the region
- How environmental conditions conducive to wildfires developed

As temperatures increase, the snow and ice in Alaska melts, which decreases the albedo of the surface. A lower albedo leads to a greater absorption of energy, which increases the temperature even more. Warmer temperatures can reduce precipitation, leading to dry conditions conducive to the development and spread of wildfires.

Task 3. Using Google Slides or a similar platform, create a presentation to teach your partner about the climate factors related to the wildfires in Alaska during the Summer 2019. The rubric that will be used to evaluate each presentation is found on the last page of the activity. Your presentation should include the following components:

- **Background:** Describe the location in terms of geographic information and a general description of the location's climate.
    - Incorporating maps and images is highly encouraged!

- **Climate Factors:** Describe how and why the climate of the location was impacted during the Summer 2019 based on the data from Tasks 1 and 2.
    - Use the information from Q1 to Q4 to help you.
    - At least one Panoply map each from Task 1 and Task 2 should be included in your slides.

- **Explanation:** Explain why the change in climate conditions led to wildfires based on the information learned from all lessons. You should also include information from FIRMS, a NASA-based system that shows the locations of wildfires. With this source you can show how the number of wildfires during the Summer 2019 was greater compared to the same months in earlier and later years. Below is a description of how to use FIRMS.
    1. Go to this link to access FIRMS and locate Alaska.
    2. ***The following is an example and can be applied to any date.*** Using the window on the right side of the screen, click on the **Advanced** tab. Next, click on the calendar to change the date to **February 1, 2017**. Then, click on "**1 day**" and change that to "**4 weeks**". Finally, only check the box that states **VIIRS 375m/Suomi NPP**. The window should now look like the following:

    3. Use FIRMS to create three maps that shows how the number of wildfires has changed based on the following time constraints:
        a. One map **during** the month & year of the specified time period

   b. One map exactly **one year before** the month & year of the specified time period
   c. One map exactly **one year after** the month & year of the specified time period

4. Take a screenshot of each map and include them in your presentation to emphasize how environmental conditions led to wildfires during the specified time period.

XIII. References

Adler, R.F., Huffman, G.J., Chang, A., Ferraro, R., Xie, P., Janowiak, J., Rudolf, B., Schneider, U., Curtis, S., Bolvin, D., Gruber, A., Susskind, J., & Arkin, P. (2003). The version 2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979-present). *Journal of Hydrometeorology, 4*(6), 1147-1167**.** Retrieved August 25, 2020 from https://psl.noaa.gov/data/gridded/data.gpcp.html

Carlowicz, M., & Schollaert Uz, S. (2017, February 17). *El niño*. NASA Earth Observatory. https://earthobservatory.nasa.gov/features/ElNino

Dauphin, L. (2020, August 7). *Another intense summer of fires in Siberia.* NASA Earth Observatory. https://earthobservatory.nasa.gov/images/147083/another-intense-summer-of-fires-in-siberia

Earth Science Communications Team at NASA's Jet Propulsion Laboratory. (2020, August 21). *The study of Earth as an integrated system.* NASA's Global Climate Change. https://climate.nasa.gov/nasa_science/science/

Earth System Research Laboratories. (n.d.). *Multivariate ENSO Index Version 2 (MEI.v2).* NOAA. Retrieved August 25, 2020 from https://psl.noaa.gov/enso/mei/data/meiv2.data

GISTEMP Team. (2020). *GISS Surface Temperature Analysis (GISTEMP), version 4*. NASA Goddard Institute for Space Studies. Retrieved August 25, 2020 from https://data.giss.nasa.gov/gistemp/

Gray, E. (2019, September 10). *Satellite data record shows climate change's impact on fires.* NASA Global Climate Change. https://climate.nasa.gov/news/2912/satellite-data-record-shows-climate-changes-impact-on-fires/

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Leetmaa, A., Reynolds, B., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Jenne, R., and Joseph, D. (1996). The NCEP/NCAR 40-Year Reanalysis Project. *Bulletin of the American Meteorological Society*, *77*(3), 437-472. Retrieved August 25, 2020, from http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP-NCAR/.CDAS-1/.MONTHLY/.Intrinsic/.MSL/.pressure/%28mb%29unitconvert/a:/:a:/T/%28Jan%201981%29%28Dec%202010%29RANGE/yearly-climatology/sub/:a/DATA/2/STEP/datafiles.html

Lenssen, N. J., Schmidt, G. A., Hansen, J. E., Menne, M. J., Persin, A., Ruedy, R., & Zyss, D. (2019). Improvements in the GISTEMP uncertainty model. *Journal of Geophysical Research: Atmospheres*, *124*(12), 6307-6326. https://doi.org/10.1029/2018JD029522

Lynch, P. (2016, June 29). *El Niño could drive intense season for Amazon fires.* NASA. https://www.nasa.gov/feature/goddard/2016/el-ni-o-could-drive-intense-season-for-amazon-fires

NASA. (2020, July 2). *NASA's aqua satellite shows Siberian fires filling skies with smoke.* NASA. https://www.nasa.gov/image-feature/goddard/2020/nasas-aqua-satellite-shows-siberian-fires-filling-skies-with-smoke/

NASA. (n.d.). [Image of sea surface temperature anomalies, tracking the upwelling of warmer-than-average water in the Eastern Pacific Ocean.]. IFLS. https://www.iflscience.com/environment/el-nino-definitely-ended-climate-change-nightmares-here-stay/

NASA. [NASA Videos]. (2019, September 10). *Carbon emissions from fires: 2003 – 2018.* [Video]. YouTube. https://www.youtube.com/watch?v=ksUIq3F8HoI&feature=youtu.be

NASA Earth Observatory. (2013, May 26). *Arctic amplification.* NASA Earth Observatory. https://earthobservatory.nasa.gov/images/81214/arctic-amplification

NASA Earth Observatory. (2019, September 27). *Mapping the Amazon.* NASA Earth Observatory. https://earthobservatory.nasa.gov/images/145649/mapping-the-amazon

NASA Earth Observatory. (n.d.). *Fire.* NASA Earth Observatory. https://earthobservatory.nasa.gov/global-maps/MOD14A1_M_FIRE

NASA's Goddard Space Flight Center. (2019, February 28). *2015-2016 El Niño triggered disease outbreaks across the globe.* [Video]. Goddard Media Studios. https://svs.gsfc.nasa.gov/13152

NASA's Goddard Space Flight Center. (2019, August 13). *NASA studies how Arctic fires change the world.* [Video]. Goddard Media Studios. https://svs.gsfc.nasa.gov/13281

NASA/NOAA. (2020, August 21). [Graph of temperature anomaly data showing rapid warming in the past few decades, the latest data going up to 2019]. https://climate.nasa.gov/scientific-consensus/ https://climate.nasa.gov/system/internal_resources/details/original/1987_yearly_temperature_anomalies_from_1880_to_2019.jpeg

National Snow & Ice Data Center. (n.d.). *The Arctic oscillation, winter storms, and sea ice.* National Snow & Ice Data Center. https://nsidc.org/cryosphere/icelights/2012/02/arctic-oscillation-winter-storms-and-sea-ice

New York State Education Department. (2020, February 25). *Science Regents Examinations: Physical Set Earth Science*. Retrieved August 25, 2020, from http://www.nysedregents.org/earthscience/

Next Generation Science Standards. (n.d.). *Topic arrangements of NGSS*. Retrieved August 25, 2020, from http://www.nextgenscience.org/overview-topics

NOAA. (2016, January 18). *El Niño and La Niña frequently asked questions.* NOAA. https://www.climate.gov/news-features/understanding-climate/el-ni%C3%B1o-and-la-ni%C3%B1a-frequently-asked-questions

NOAA. (2016, January 18). [Map of sea surface temperature anomalies in the Pacific Ocean during a strong El Niño in December 1997]. https://www.climate.gov/news-features/understanding-climate/el-ni%C3%B1o-and-la-ni%C3%B1a-frequently-asked-questions https://www.climate.gov/sites/default/files/iconic_ENSO_elNino_lrg.jpg

NOAA. (2016, January 18). [Map of sea surface temperature anomalies in the Pacific Ocean during a strong La Niña in December 1998]. https://www.climate.gov/news-features/understanding-climate/el-ni%C3%B1o-and-la-ni%C3%B1a-frequently-asked-questions https://www.climate.gov/sites/default/files/iconic_ENSO_laNina_lrg.jpg

NOAA. (n.d.). *El Niño Southern Oscillation.* [Diagram]. The Globe Program. https://www.globe.gov/web/el-nino

Prentice Hall Inc. (2007). Pearson. http://www.pearsoned.ca/highered/mygeoscienceplace/ElNinoLaNina.html

R Programming 101. (2019, January 28). *How to install R and install R Studio. How to use R studio | R programming for beginners* [Video]. YouTube. https://www.youtube.com/watch?v=orjLGFmx6l4

Smith, T. M., Reynolds, R. W., Peterson, T. C., & Lawrimore, J. (2008). Improvements to NOAA's historical merged land–ocean surface temperature analysis (1880–2006). *Journal of Climate*, *21*(10), 2283-2296. Data retrieved August 25, 2020 from https://doi.org/10.5067/ERSST-L4N40

Stevens, J. [NASAEarthObservatory]. (2017, February 14). *The birth and death of an El Niño.* [Video]. YouTube. https://www.youtube.com/watch?v=69N494UIlS8&feature=emb_title

UCAR. (n.d.). *Teleconnections: changes in weather linked together.* UCAR Center for Science Education. https://scied.ucar.edu/teleconnections-changes-weather-linked-together

UCAR. (n.d.). *The highs and lows of air pressure.* UCAR Center for Science Education. https://scied.ucar.edu/learning-zone/how-weather-works/highs-and-lows-air-pressure

Viñas, M. J. (2019, August 13). *NASA studies how Arctic wildfires change the world.* NASA Global Climate Change. https://climate.nasa.gov/news/2902/nasa-studies-how-arctic-wildfires-change-the-world/

XIV. Acknowledgements

- Thank you to NASA Science Mission Directorate, NASA GSFC Office of Education (160) and the NASA GISS Climate Change Research Initiative (CCRI) program for the wonderful opportunity to create these lesson plans.

- Thank you to Matthew Pearce, Educational Program Specialist at NASA GISS, for all of his encouragement and support.

- Thank you to Dr. Allegra LeGrande for her tremendous support of teachers and education, and all of her guidance for the past six years.

- ANL and Nicole Dulaney thank NASA Goddard Institute for Space Studies for institutional support.

- ANL and Nicole Dulaney also thank NASA Center for Climate Simulation, GISTEMP Team, NASA-Model Analysis and Prediction, NASA-Energy and Water Cycle, GISS ModelE RTOP, NASA Earth Science programs, and program managers David Considine and Jack Kaye for this opportunity.

- A very special thank you to NASA GISS scientists Nathan Lenssen, Gavin Schmidt, James Jansen, Matthew Menne, Avraham Persin, Reto Ruedy, and Daniel Zyss for the significant contribution to Lesson #4 – Atmospheric Teleconnections. The GISTEMP data and RScripts will forever allow students to make connections between average global surface temperature and ENSO.